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THESIS

DEVELOPMENT OF A HUMAN SYSTEMS INTEGRATION FRAMEWORK FOR COAST GUARD ACQUISITION

by

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June 2014

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Human systems integration (HSI) applies knowledge of human capabilities and limitations to design more efficient, effective and safe military systems. HSI can enable impressive lifecycle cost savings and performance gains when implemented. In practice, HSI activities are hampered by the complexity of human-technology integration issues. This thesis develops a simplified framework for understanding and assessing HSI throughout the acquisition process.

An HSI Activity Model is presented to conceptualize HSI activity in military acquisition. Established human factors and human computer interaction theories are applied to develop a concise view of HSI in action. The core activity of HSI is summarized as the balancing of human capabilities and limitations with the affordances and constraints presented by system technology, to accomplish system objectives.

A Comprehensive Human Integration Evaluation Framework (CHIEF) is then developed to provide the acquisition community with a viable tool for assessing HSI during acquisition. A measurement approach, rating scales and criteria, and a consolidated scoring matrix are developed based on lessons gathered from current system assessment measures, and refinement with HSI practitioners.

If implemented, the HSI Activity Model and CHIEF offer the potential to increase HSI understanding and awareness, leading to improved system outcomes across the DHS acquisition enterprise.

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DEVELOPMENT OF A HUMAN SYSTEMS INTEGRATION FRAMEWORK FOR COAST GUARD ACQUISITION

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LIST OF ACRONYMS AND ABBREVIATIONS

APF	acquisition performance factor
AT	activity theory
CHIEF	comprehensive human integration evaluation framework
DAG	defense acquisition guidebook
DAM	dynamic anthropometric modeling
DHS	Department of Homeland Security
DI	Design Interactive
DOD	Department of Defense
ESOH	environmental safety and occupational health
FAST	fatigue avoidance scheduling tool
FOM	figure of merit
FRC	Fast Response Cutter
HCI	human computer interaction
HF	human factors
HFE	human factors engineering
HFI	human factors integration
HSI	human systems integration
HSIL	human systems integration level
INCOSE	International Counsel on Systems Engineering
IPT	integrated product team
MSAM	U.S. Coast Guard Major Systems Acquisition Manual
MDA	Milestone Decision Authority
NASA	National Aeronautics and Space Administration
NPS	Naval Postgraduate School
PRR	Production Readiness Review
PS&T	performance support and training
SBIR	small business innovation request
SE	systems engineering
SELC	systems engineering lifecycle concept

SHARE	system for human factors analysis
SRL	system readiness level
TRA	technology readiness assessment
TRL	technology readiness level
TSPI	total system performance implication
TTAM	tools, techniques, approaches and methods

EXECUTIVE SUMMARY

Human systems integration (HSI) incorporates knowledge of human capabilities and limitations into the design of modern systems to make them more efficient, effective and safe (Booher, 2003). When implemented in a timely fashion, HSI can drive impressive cost savings and performance gains (Booher, 1997; Liu, Valerdi, & Rhodes 2009). In application, HSI is hampered by the complexity of human-technology integration issues (Newman, Bruseberg, Lowe, Borras, & Tatlock, 2008; Boff, 1990). This thesis presents two products to enhance understanding of HSI during military acquisition: a conceptual model, and an assessment framework.

The HSI activity model conceptualizes HSI activity during military acquisition. Established human factors and human-computer interaction theories were applied to military acquisition to develop a concise view of HSI in action. The model summarizes the core activity of HSI as the balancing of human capabilities and limitations with the affordances and constraints presented by system technology to accomplish system objectives (Figure 1).

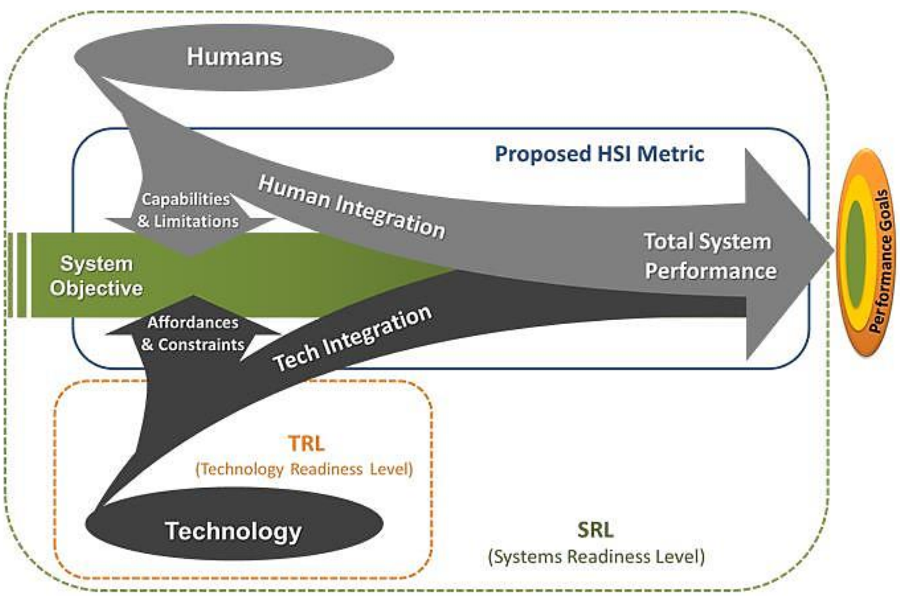

Figure 1. Proposed HSI activity model.

The Comprehensive Human Integration Evaluation Framework (CHIEF) was developed to provide the acquisition community with a viable tool for assessing HSI during acquisition. Systems assessment measures, including NASA/DOD technology readiness levels (TRL), were analyzed to determine criteria for a successful measure. The measurement approach, rating scales and criteria, and a consolidated scoring matrix were developed in collaboration with faculty from the Naval Postgraduate School. Elements of CHIEF were then refined during a series of workshops with practitioners from the Coast Guard Human Systems Integration Division (CG-1B3). As a culminating exercise, the practitioners evaluated the usability of CHIEF by conducting a mock HSI evaluation for a current major acquisition program. The finalized CHIEF framework elements are presented in Figure 2.

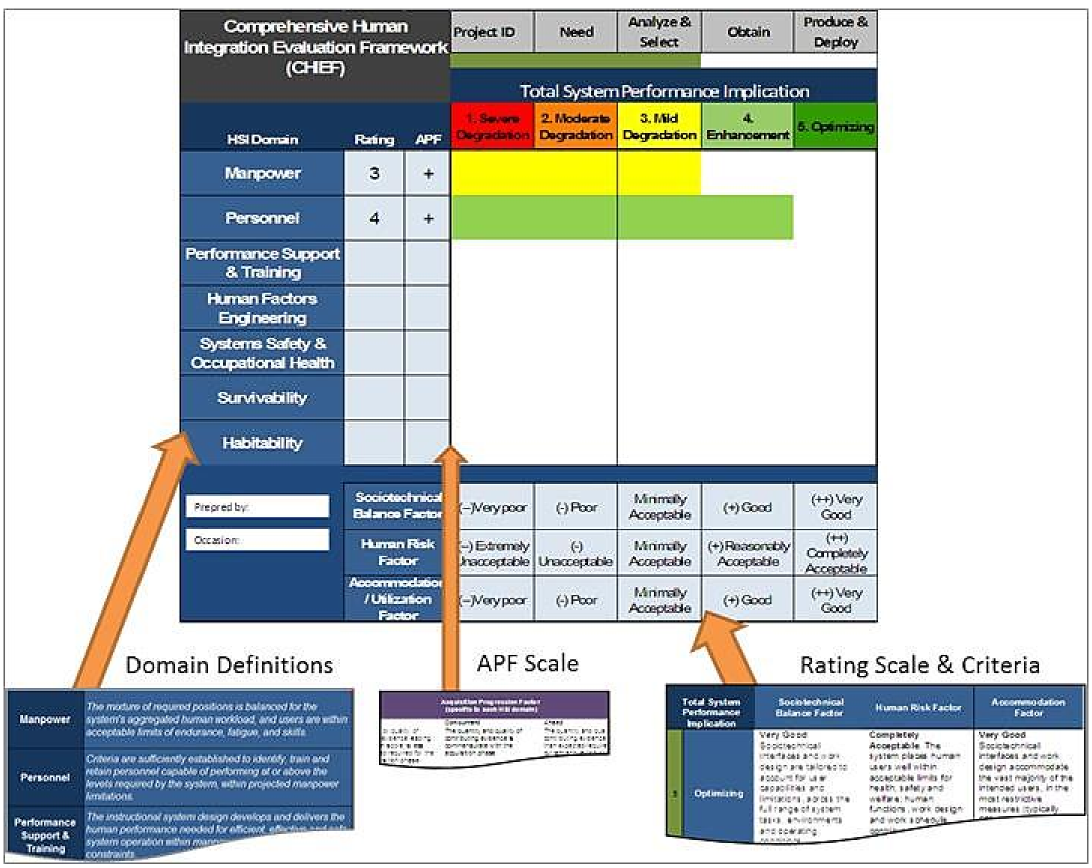

Figure 2.Comprehensive Human Evaluation Framework (CHIEF) elements

Areas for expanded investment and research include the development of dedicated CHIEF software, identification of measures to support the framework, and refinement of rating scales and criteria based on organizational needs. If implemented, the HSI Activity Model and CHIEF offer the potential to increase HSI understanding and awareness during the acquisition process, leading to improved system outcomes across the DHS acquisition enterprise.

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I. INTRODUCTION

A. WHAT IS HUMAN SYSTEMS INTEGRATION?

Human systems integration (HSI) is an amalgam of many fields, unified by a pragmatic purpose: to understand human capabilities and limitations and apply this knowledge to system design (Chapanis, 1996; Booher, 2003). HSI has been described as a management concept, a design philosophy, and a technical approach centered on human users of modern systems (Booher, 2003). The International Council on Systems Engineering (INCOSE) Handbook captures this purpose: “The primary objective of HSI is to ensure that human capabilities and limitations are treated as a critical system element, regardless of whether humans in the system operate as individuals, crews, teams, units, or organizations.” (Haskins, Forsberg, Krueger, Walden, & Hamelin, 2006, p. 326)

HSI is deeply rooted in the field of human factors (HF), originating from studies of task efficiency among factory workers in the early 1900s. By mid-century, research in human factors engineering (HFE) enabled better understanding of how man interacts with technology (Figure 1). This knowledge was integrated into the increasingly complex technological systems that emerged from the Second World War (Chapanis, 1996; Tvaryanas, 2010).

Figure 1. Human factors during WWII (from DVI Aviation, Inc)

Our expanding knowledge of human-technology interaction led to more diverse approaches in the latter half of the 20th century. New ways to integrate human considerations into systems development were conceived, and areas of research were expanded to involve multiple domains. Rather than focusing narrowly on individual workstation or task design, practitioners addressed staffing policies, training approaches, and the effects of health and safety on overall system performance (Chapanis, 1996, Tvaryanas, 2010). These considerations became a key factor in the evaluation of system performance. With the advent of the U.S. Army's MANPRINT program in the late 1980s, HSI was incorporated into modern military system acquisition (Booher, 2003, Tvaryanas, 2010).

Organizations across the DOD and federal government recognize different domains within the HSI discipline. This thesis adopts the seven domains recognized by the U.S. Coast Guard: human factors engineering, personnel, manpower, performance support and training, systems safety and occupational health, survivability, and habitability (Figure 2).

Human Factors Engineering (HFE): Employed during systems engineering over the life of the program to provide for effective human-machine interfaces and to meet HSI requirements.

Personnel: Define the human performance characteristics of the user population based on the system description and projected characteristics of target occupational specialties. Personnel attributes are design parameters.

Manpower: The mix of military, civilian, and contract support necessary to operate, maintain, train and support the system.

Performance Support and Training (PS&T): Develops options for individual, collective, and joint training for operators, maintainers and support personnel, consistent with FORCECOM policies and, where appropriate, base training decisions on training effectiveness evaluations. The PM shall address the major elements of training, and place special emphasis on options that enhance user capabilities, maintain skill proficiencies, and reduce individual and collective training costs.

System Safety and Occupational Health (SS/OH): This domain integrates across disciplines and into systems engineering to determine system design characteristics that can minimize the risks of acute or chronic illness, disability, or death or injury to operators and maintainers; and of equipment damage, failure or loss.

Survivability: Addresses personnel survivability issues including protection against detection, fratricide, Chemical, Biological, Nuclear, Radiation and High-Yield Explosives (CBNRE) effects; the integrity of the crew compartment; and provisions for rapid egress.

Habitability: Establishes requirements for the physical environment, personnel services (e.g., medical and messing), working and living conditions (e.g., berthing and personal hygiene).

Figure 2. USCG HSI domains (from Acquisition Directorate, 2010)

HSI is not a collection of discrete disciplines, but various domains sharing a set of concepts and similar language. In practice, the borders between domains are porous and their contents are interrelated (Booher, 2003). The labels differentiating domains are mainly a convenient taxonomy that suggests the perspectives from which human-centered design issues may be understood.

B. HSI IN PRACTICE

HSI contains a rich body of knowledge spanning more than a century of research in the social, physical, and cognitive sciences. HSI and HF research offers empirically-grounded understanding of human capabilities and limitations, and time-tested sociotechnical design principles to the acquisitions community of practice (Chapanis, 1996). HSI Practitioners employ this specialized knowledge with a robust suite of tools, techniques, and methods (Hale, Ching, Brett, & Rothblum, 2009) to investigate the integration of man and machine in modern systems.

HSI practitioners work in integrated product teams (IPTs) across every phase of military acquisition (USCG Acquisition Directorate, 2010). They contribute early by providing input to mission need statements (MNSs) and operational requirements documents (ORDs). As a system's functional and physical architecture begins to take shape, practitioners work across functional areas to incorporate human-centered design principles. In later stages, practitioners facilitate human-centered program management, contracting, and test and evaluation (T&E) activities.

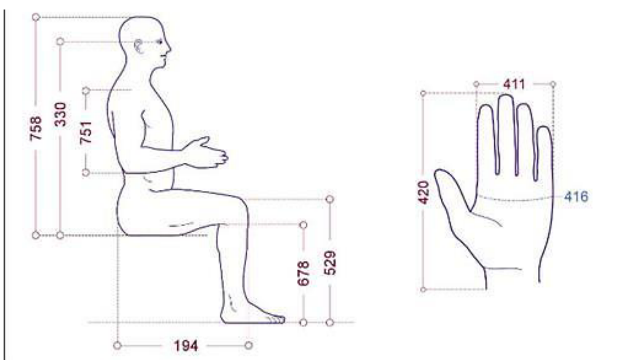
HSI practitioners come from diverse disciplines and professional backgrounds. Qualifications range from graduate and undergraduate degrees in the human sciences to professional certifications (Kleiner & Booher, 2003; Chapanis, 1996). While their backgrounds and expertise vary, HSI practitioners occupy a distinctive role in acquisition. They advocate for system operators, maintainers, and supporters by ensuring that systems attributes are designed to support their needs.

C. HSI REALIZATIONS

Decades of HF and HSI have revealed a number of important realities concerning human-centered design. This section addresses several critical themes.

1. It Is Hard to Get HSI Right

Human beings are deceivingly complex, and the questions that arise in intermingling people with technology warrant very careful study. Anthropometry (the science of measuring the parameters of the human body) is but one example of human complexity. Properly derived anthropometric design ensures that a system will physically accommodate its intended users (Pheasant & Haslegrave, 2005). Anthropometric conformance is often addressed by applying the “5th–95th percentile” criterion (Blanchard & Fabrycky, 2011; NASA, 2010). This criterion mandates that a system accommodate all users that fall within the 5th to 95th percentile (central 90 percent) for relevant physical measurements. In commercial application, the use of anthropometrics is seen in the adjustability of driver seats to ensure that a wide range of customers can operate a vehicle’s controls effectively. A sampling of anthropometric measures common to commercial and military applications is shown in Figure 3.



No.	Dimension	Min (cm, (in))	Max (cm, (in))
758	Sitting height	77.7 (30.6)	101.3 (39.9)
330	Eye height, sitting	66.5 (26.2)	88.9 (35.0)
529	Knee height, sitting	45.5 (17.9)	63.5 (25.0)
678	Popliteal height	33.0 (13.0)	50.0 (19.7)
751	Shoulder-elbow length	29.6 (11.6)	41.9 (16.5)
194	Buttock-knee length	52.1 (20.5)	69.9 (27.5)

Figure 3. Basic anthropometric measures (from NASA, 2010)

Accounting for height, reach, leg length and other body measurements in design might appear to be a simple matter of data retrieval: find the applicable database (as in Figure 3), select the measurement (e.g., arm length), and design to accommodate the desired range of measures. In most cases a significantly more detailed anthropometric analysis must be applied. A person with long legs, for instance, will not necessarily have a long torso, or long arms, as Figure 4 illustrates.

Figure 4. Differences between measures for two individuals with identical seated height (from McCauley, 2014)

Humans are not constructed with uniform proportions (Pheasant & Haslegrave, 2005). Humans are in fact so variable that the differences seen in Figure 4 are common across nearly every physical measure (Moroney & Smith, 1972). Because human variability is so pervasive, simplistic approaches are often problematic. The development of 21st century military systems has confirmed that a refined, multivariate analysis is required to calibrate systems to users (Lockett, Kozycki, Gordon, Bellandi, 2005). Multivariate analysis (Figure 5)

accounts for all potential combinations of individual anthropometric measures, using specialized modeling software (Lockett et al., 2005; NASA, 2010).

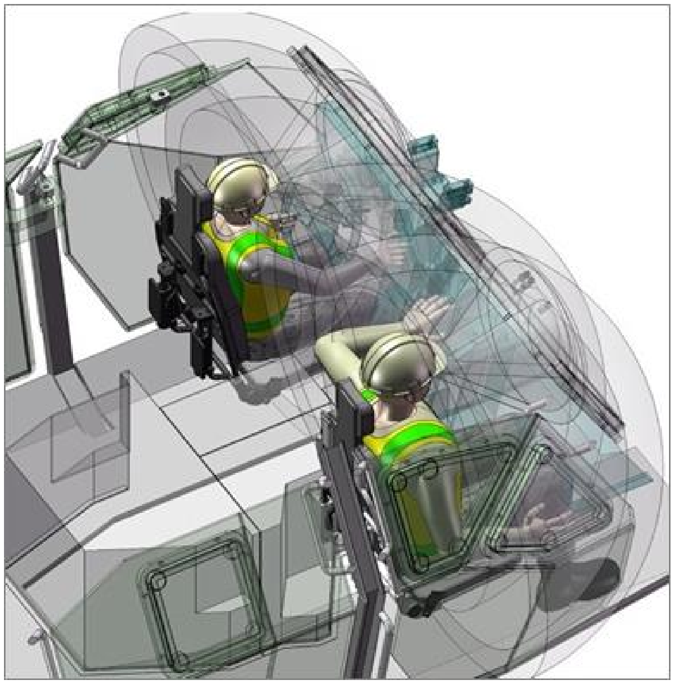


Figure 5. Reach envelopes calculated for different users (from Ergo-Link by Sun Group Design, LLC)

Consider that a task as simple as pressing a button on a console involves more than ten anthropometric measures (Pheasant & Haslegrave, 2005) and countless potential paths of movement. When the complexity of this physical task is coupled with the complexity of the cognitive processes that guide human movement, the challenging nature of designing human–technology interfaces becomes apparent.

2. HSI Is Inevitable

Jakob Nielsen, co-founder of the Nielsen-Norman consulting group and former vice president of research at Apple Computer, once had this to say regarding the testing of a new product:

> your system will be tested for usability even if you don't do so yourself. Your customers will do it for you, as they struggle to use

> the system. Any usability problems found by users in the field will undermine your reputation for quality products and the resulting change requests will be about 100 times more expensive to implement than changes discovered by yourself in the early phases of the project. (Nielsen, 1993, pp. 7–8)

The true customers in a military acquisition are military users. It is these operators, maintainers, and supporters who eventually transform an assembly of technologies we know as a “system” into a “capability” (Booher, 2003). Even in the case of unmanned or autonomous systems, living users contribute directly or indirectly to almost every function (Murphy and Shields, 2012). Like users of commercial products, military users determine a system’s success or failure. However, unlike civilian consumers, military users often have less discretion in selecting the equipment they use to complete their tasks.

In the consumer world, a system poorly calibrated to a customer's capabilities and limitations may lead to poor product ratings and limp sales (Nielsen, 1993). But poor HSI in a military system may bring error, mishap, and injury that may otherwise have been avoided (Booher, 1997; Tvaryanas, 2006). Beyond the vicissitudes of corporate fortunes, mission outcomes, and thus human lives, hang in the balance. The nature of military HSI demands that we identify and remove system performance detractors to the full extent of system resources.

Systems eventually end up in the hands of users. Poor design elements are exposed, and changes will inevitably result. The lesson for military systems is straightforward: changes will always be necessary to make products suitable for operational use; it becomes a simple matter of how much we want to pay.

3. HSI’s Timing Is Critical

As the Coast Guard and DHS develop increasingly complex systems under tighter fiscal and manpower constraints, timely and effective HSI involvement grows increasingly important (Boff, 1990; Chapanis, 1996; Booher,

2003). Solving problems in human–technology integration is easily deferred in the immediacy of ensuring that system technology is being developed as scheduled and within cost constraints. While meeting deadlines and schedule constraints may be hallmarks of a well-executed acquisition, early identification and implementation of HSI-driven design improvements are also critical to a program's ultimate success (Booher, 2003, Miller et. al., 2003).

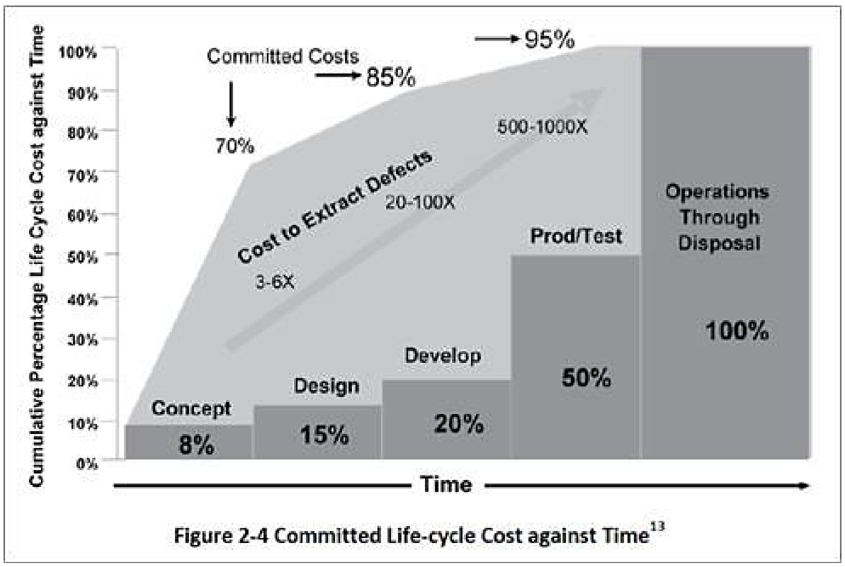


Figure 6. The cost of system changes over time (from the INCOSE handbook)

As seen in Figure 6, postponing HSI has a price tag. The costs associated with delaying HSI-related design changes increase quickly as a system matures (Blanchard & Fabrycky, 2011; Haskins et al., 2006). For example, it may become apparent that the operating console on the bridge of a new Coast Guard cutter should be relocated to improve watch awareness and maintenance access. In the early stages of acquisition, the console can be relocated with mouse-clicks in the design software. If the change is delayed until production has begun, a formal engineering change must be initiated, requiring extensive management and contracting overhead, in addition to material and labor costs. Figure 7, adopted from *Systems Engineering & Analysis*, 5th edition, illustrates this point.

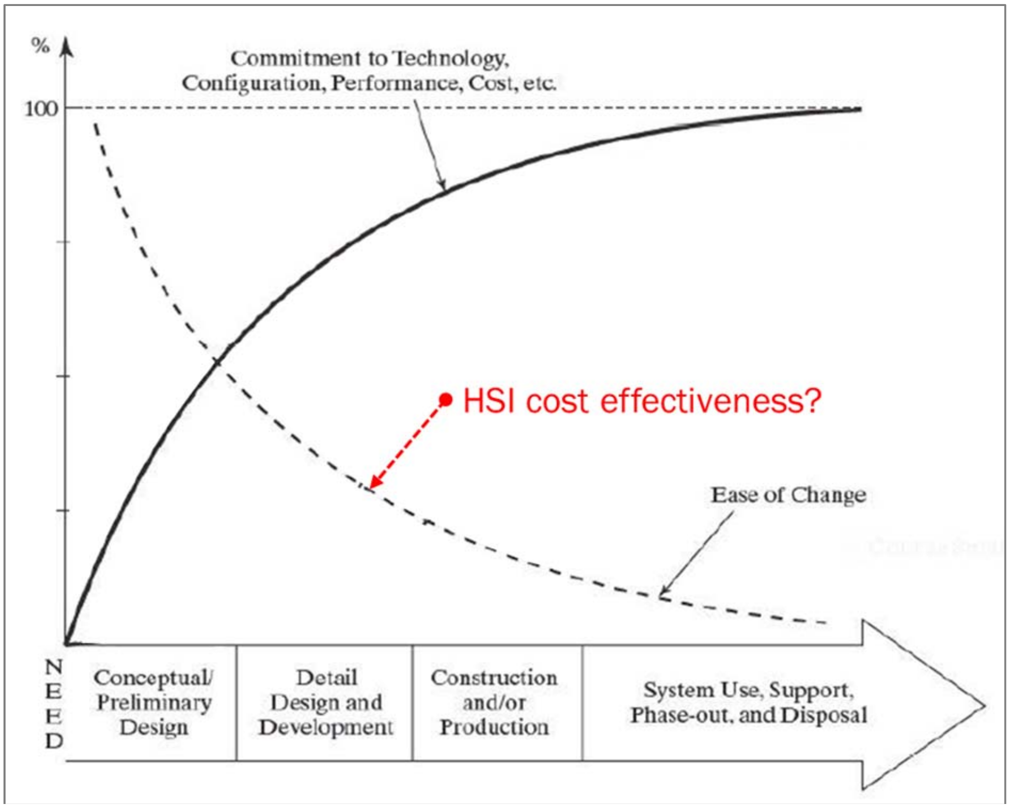


Figure 7. HSI cost effectiveness over time
(after Blanchard & Fabrycky, 2011)

HSI makes systems better by ensuring that technological systems marry well with the realities of their human users. Designing effective, efficient, and safe systems for our service members requires careful, comprehensive, and timely human–technology integration. As commercial industry teaches us, changes are inevitable as human and technological elements of a system come together. What is not inevitable, however, is incurring excess cost because of these changes. Deferring HSI to the late stages of acquisition is enormously expensive. In military acquisition, the choice is ours: how much will we ask taxpayers to pay?

D. THE IMPETUS FOR THIS THESIS

The Human Factors and Behavioral Sciences Division of the Department of Homeland Security (DHS) published “A Vision for Human Systems Integration in the U.S. Department of Homeland Security” in 2009. The article identified ten

keys to implementing HSI within DHS. First among these was the following: “Standardize and institutionalize the process for embedding HSI into the DHS Technology Readiness Level [TRL] framework” (Wilson, Malone, Lockett-Reynolds, & Wilson, 2009, p. 2).”

DHS’s emphasis on integrating human concerns into technological development is not surprising. In the next chapter, our study of the NASA/DOD TRL scale will reveal a framework that enables technology to be managed across diverse acquisition disciplines in a timely and effective manner. By contrast, few frameworks exist for evaluating how users integrate with technology (Johnston et al., 2013; Phillips, 2010). Stated plainly, human-integration considerations are at a severe disadvantage in the acquisition process, as compared to technologically driven requirements.

The USCG and DHS are not the only organizations faced with this challenge. Implementing HSI and HF effectively is a mounting concern within the Department of Defense (DOD) and other federal agencies, the U.K.’s ministry of defense (MoD), and the commercial sector (Johnston et al., 2013; Earthy et al., 1999). Although developmental measures have been proposed, there is no widely accepted framework for evaluating HSI throughout the acquisition lifecycle.

This thesis proposes a conceptual model of the core activity of HSI and a framework for assessing HSI during acquisition. If successfully implemented, these products are expected to illuminate human-technology integration issues, allowing improved outcomes across the USCG/DHS acquisitions enterprise.

The next chapter examines the development and emergence of the NASA/DOD TRL scale, which is widely used for technology readiness assessment in federal acquisition. Recently proposed human–technology integration measures are also examined and compared with TRL to establish criteria for an HSI assessment framework.

II. A REVIEW OF CURRENT SYSTEM READINESS MEASURES

While a number of measures have been developed to assess system readiness, assessing human-technology integration is a relatively new undertaking (Phillips, 2010; Johnston et al., 2013). In this section, the NASA/DOD TRL scale is analyzed and compared with two developmental human-technology assessment frameworks (SHARE and HRL). Important links between these assessment frameworks and the TRL scale are noted and the drawbacks of using the scale's structure to assess HF and HSI are identified.

A. LESSONS FROM THE EMERGENCE OF NASA/DOD TECHNOLOGY READINESS LEVEL SCALE

The NASA/DOD TRL scale is now widely accepted in federal acquisition (Johnston et al., 2013, Mankins 2009). This scale focuses exclusively on technology, and makes no attempt to account for human contributions to a system (Phillips, 2010). Nevertheless, its conception and successful propagation throughout the acquisition community offers lessons for establishing a viable systems assessment measure. To understand the importance of the TRL scale, some historical context is required.

During America's quest to dominate space in the 1970s, NASA was charged with integrating cutting-edge technology into spacecraft at an extraordinary rate. At the time, technology readiness assessment (TRA) was the chief methodology for ensuring technological components were suitably mature for NASA missions (Mankins, 2009). Assessments were conducted at multiple points in the development lifecycle, requiring detailed technical requirements to be translated across government, commercial, and scientific circles. The need to develop a unified standard for technology readiness soon became evident, and what we now know as the TRL scale emerged (Mankins, 1995; Mankins, 2009).

The current TRL scale divides technological readiness into nine simply defined levels. The scale produces "a discipline-independent, program figure of

merit" (Mankins, 2009, p. 1216) with which to assess and communicate the maturity of a new technology. This allows complex technology readiness requirements to be understood and applied across disciplines. In a recent retrospective, John Mankins, a 25-year veteran at NASA, highlighted the TRL scale as "the foundation of modern technology readiness assessment" (Mankins, 2009, p. 1217). This foundation has shaped NASA technology development for more than three decades. The current version of the TRL scale appears in Figure 8.

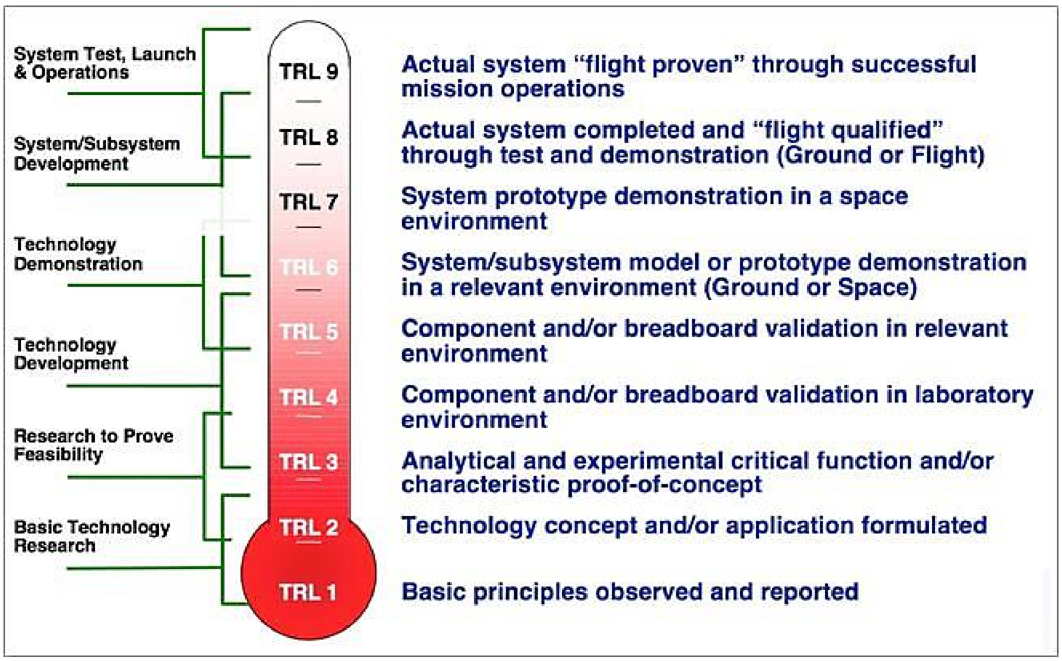


Figure 8. The NASA TRL scale (from NASA, 2012)

More than three decades after implementation, users of the TRL scale include DHS, USCG, DOD, and government organizations throughout the world (Mankins, 2009; USD (AT&L), 2011).

The most convincing evidence of the TRL scale's utility may be found in its absence. Consider the task of evaluating a new engine technology for an aircraft acquisition program without the benefit of such a scale. The new engine promises an appreciable performance advantage over older technology, but has

yet to be demonstrated in a similar application. Successful implementation of this technology would require program managers, systems engineers, operational testers, contract specialists, and experts in multiple engineering areas to evolve specific performance criteria for the new engine. Reaching agreement among all parties would require considerable time and effort. Today, we can expedite this process by identifying the desired TRL. The common benchmark set by the TRL scale can then be expanded upon as necessary within each discipline involved in the acquisition program.

Current challenges in assessing HSI closely parallel those faced by NASA and other agencies before the TRL scale was devised. HSI activities must be coordinated across disciplines without the benefit of a standardized assessment framework (Phillips, 2010; Wilson et al., 2009). Instead, today's HSI practitioners must define, prioritize, and translate the desired state of human-technology integration on an issue-by-issue basis.

B. REVIEW OF HUMAN FACTORS-RELATED SYSTEM READINESS MEASURES

A review of government, commercial, and academic literature reveals two relevant models for assessing HSI during system acquisition. Since both models are new to acquisition, limited information is available on their effectiveness in actual programs. In this section, the merits and limitations of these models are discussed and compared with the characteristics of the TRL scale.

1. System for Human Factors Readiness Evaluation and Human Factors Readiness Levels

In 2008, the FAA initiated a sweeping update of the U.S. air traffic control system with the NextGen program, promising a top-to-bottom overhaul of aging air traffic control technologies. The FAA quickly acknowledged the role of human factors in NextGen's success and authored a Small Business Innovation Request (SBIR) seeking industry assistance to provide specific tools for this purpose. A two-phase contract was awarded to Design Interactive (DI), Inc., for a software

tool to improve NextGen outcomes by standardizing and automating human factors assessment. DI created two related products, System for Human Factors Readiness Evaluation (SHARE), a computer-based system for tracking identified HF issues, and Human Factors Readiness Levels (HFRL), a scale for prioritizing the resolution of these issues (Design Interactive, 2012; Johnston et al., 2013).

The first iteration of SHARE defined nine levels of HF readiness, aligning HFRL directly with the TRL scale. This initial HFRL configuration defined key human factors activities, and then separated them into graduated levels, similar to the TRL scale. DI's initial concept for the scale is seen in Figure 9.

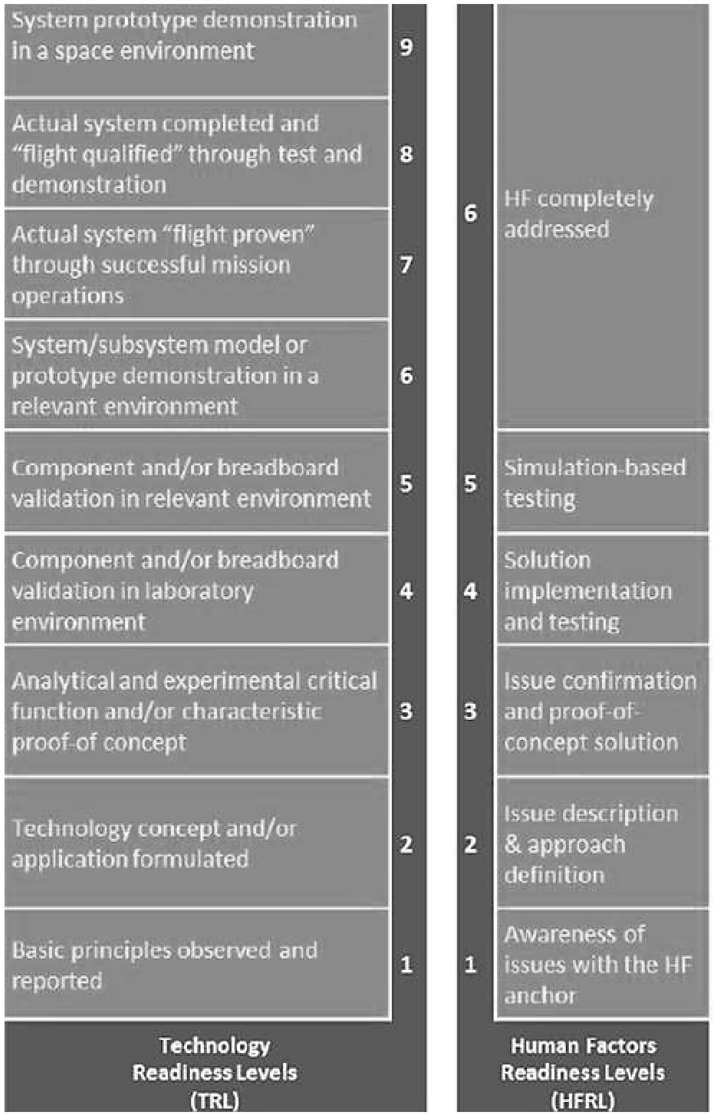


Figure 9. Initial concept for HFRL (from Design Interactive, 2012)

At Phase I review, FAA officials identified several drawbacks to this approach. Critically, the process-focused levels did not address actual outcomes of HF analysis and testing. HFRL scores could increase based on the completion of HF analysis and testing alone, even if outcomes were not favorable. This meant that even if a high-priority HF deficiency was discovered in late-stage testing, the system's HFRL rating would remain unchanged. The FAA concluded that the scale's inability to capture the importance of HF issues, regardless of timing, could lead to inaccurate ratings (Design Interactive, 2012).

Based on FAA feedback, DI consulted with government and commercial HF practitioners to improve SHARE and HFRL functionality (Design Interactive, 2012; Johnston, et al., 2013). DI quickly shifted SHARE development toward the assessment of actual human-technology performance, allowing for system evaluation irrespective of technology state or acquisition phase. Based on DI's findings, the second iteration of SHARE was implemented as an issue-based, risk-guided system for tracking HF readiness during system development.

This second iteration enables users to create a profile for individual HF issues as they arise during acquisition. HF practitioners can then rate each issue using a standardized FAA risk-classification scale, and catalog the issue into a specific category (e.g., anthropometrics, displays and controls). HFRL scores are tabulated across categories and across the system, based on highest (worst) risk scores (Design Interactive, 2012). The SHARE software displays these HFRL ratings in useful dashboard metrics, allowing FAA users to track HFRL across categories and over time. An early SHARE software concept screen is shown in Figure 10.

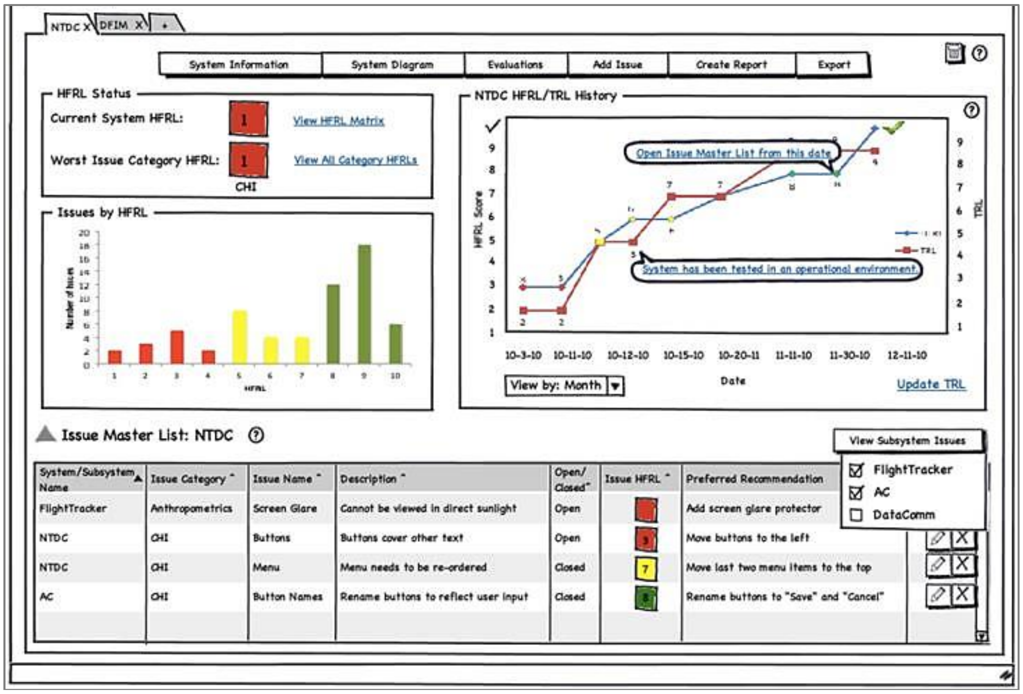


Figure 10. Early SHARE software concept (from Design Interactive, 2012)

SHARE offers a viable platform for assessing HF-related deficiencies, but has some limitations. Risk is well accepted in federal acquisition, but has inherent limitations for capturing the full spectrum of system performance (DOD, 2006). In military acquisition, system development is managed to ensure that performance remains between threshold and objective values (Defense Acquisitions University, 2010). Risk focuses on issues that fall below the threshold values, and does not evaluate performance that is above this threshold. This is useful for prioritizing HF or HSI deficiencies (Harrison & Forster, 2003), but may be inadequate for a holistic assessment of HSI performance.

Nevertheless, SHARE and HFRL offer a robust toolset for HF issue identification, classification, and resolution (Design Interactive, 2012: Johnston, et al., 2013). DI's shift from process-based metrics toward performance-based metrics during software development suggests a key lesson for the development of an HSI evaluation framework. SHARE appears well positioned to standardize

and improve HF evaluation across the FAA. For application to HSI assessment, the format and structure of SHARE may be useful in HFE and other domains, and warrants careful consideration.

2. Human Readiness Levels

The “Development and Initial Evaluation of Human Readiness Level (HRL) Framework” (2010) was a pioneering effort to establish a meaningful HSI metric in DOD acquisition. The HRL concept was conceived by Hector Acosta of the USAF 711th Human Performance Wing, and developed into the HRL framework by Major Eric Phillips, USAF. Phillips constructed HRL as a progressive scale (similar to the TRL) to synchronize HSI activity and outcomes in the DOD acquisition framework (Phillips, 2010).

Phillips used the NATO human view architecture (NATO HVA) as a conceptual basis for HRL. Introduced by the UK MoD in 2010 to supplement existing acquisitions procedures, the NATO human view describes the primary areas of human consideration required for modern system design. (For a thorough discussion on the NATO human view, see the *NATO Human View Handbook,* 2008.) Using the NATO human view, Phillips outlined criteria for developing a human readiness level scale based on current acquisition practices. These criteria included 1) adherence to accepted risk management practices; 2) implementation of HSI as early as possible in the acquisition processs; 3) emphasis on human-centered design that contributes to total system performance; and 4) capturing the incremental cost of HSI over the course of acquisition (Phillips, 2010).

To create HRL levels, Phillips conducted an extensive mapping of HSI activities, processes, and products. This mapping was then evaluated against the NATO human view and sequenced according to acquisition phase into nine levels (Phillips 2010). The resulting HRL scale and descriptions are presented in Table 1.

Human Readiness Level	Description
1. Activation of Human Systems Integration: base-lining and commitment.	Lowest level of socio-technical readiness. HSI infrastructure is setup within Systems Engineering planning. Total system analysis from both functional relationship and organizational perspectives occurs. Activity examples include front-end analyses, preliminary functional allocation, and initial HSI assessment and plan.
2. Human Systems Integration analysis suite in support of component technology development.	Significant HSI input to acquisition development and documentation occurs. Activity examples include initial human-machine interface assessment, generation of Target Audience Description, and threat/hazard assessment.
3. Component human touch point resolution (i.e., human-system interaction, to include hardware and software): refining requirements thresholds.	Multiple needs analyses and studies are conducted in support of requirement definitions. HSI domain assessments inform ongoing development actions, as well. Activity examples include human-in-the-loop analyses, sub-system hazard analysis, and HSI plan update and revision.
4. Component human touch point engineering parameters and human performance indicators.	Iterative evaluation and analysis of each HSI domain takes place and provides critical items of consideration bearing on system design. Activity examples include usability testing, development of human-centered source selection, and updating the human-machine interface assessment.
5. Limited system human performance parameters/demonstration.	Various HSI assessments and testing are performed to support the significant increase in fidelity of breadboard technology. This includes supporting "high fidelity" laboratory integration of components. Activity examples include examining safety and occupational health design features and cognitive task analyses.
6. Field (relevant environment) validation of human performance prototypes.	Representative model or prototype system is tested in a relevant environment. Evaluations of human performance embedded in demonstration system occur and HSI predictive models are updated. Activity examples include testing human reliability and usability of prototype in a high-fidelity laboratory environment or in simulated operational environment.

7. Final Developmental Test & Evaluation/human performance parameters.	Significant HSI participation in system test events occurs. Iterative evaluation and analysis of each HSI domain continues as well. Activity examples include error and fault analysis to cover human error performance, equipment operability, safety procedures, and error recovery mechanisms.
8. Operational Test & Evaluation/human performance parameters.	Special human-centric analyses are conducted to update thresholds, objectives, and evolving criteria for Operational Test & Evaluation. Iterative evaluation and analysis of each HSI domain continues as well. Activity examples include system hazard analysis and HSI domain tradeoff studies.
9. Sustainment: Initiation of capability gap feedback cycle.	Extensive and iterative review and verification of fielded system begins, as well as post-product improvement evaluations for the next incremental builds. Activity examples include post-fielding training evaluation analysis and sustaining a hazard analysis for the fielded system.

Table 1. HRL nine-level scale and definitions
(from Phillips, 2010)

HRL levels share essential features with the first HFRL concept proposed by Design Interactive. Both frameworks were constructed to coincide with the TRL scale and both focus on the completion of acquisition activities. HRL is hindered by many of the same drawbacks identified by the FAA in their evaluation of DI's initial work. Like HFRL, HRLs take a process-oriented approach. The HRL scale provides for standardization and increased awareness, but does not assess or account for HSI efficacy. This can lead to inaccurate ratings. Consider, for example, the detailed definition for HRL Level 5 (Table 1):

> Various HSI assessments and testing are performed to support the significant increase in fidelity of breadboard technology. This includes supporting high fidelity laboratory integration of components. Activity examples include examining safety and occupational health design features and cognitive task analyses. (Phillips 2010)

Even if all activities in this HRL level are completed, the extent to which human–technology integration has contributed to system performance remains unclear. Many questions remain unanswered, including:

- Were the results of HSI assessments favorable?
- Did the state of human–technology integration improve or degrade overall system performance?
- What did testing, evaluation, and analysis reveal about the human contribution to system goals?

These questions reveal an important difference between technology readiness measures (i.e., TRL) and potential human–technology integration measures. Technology outcomes are more compatible with the progressive trajectory provided by the TRL scale. Reliability analysis, for example, examines system performance over time based on individual technology components either being operable or not; mechanical components either perform or fail; software code segments function or crash, and tend to do so in predictable ways (Blanchard & Fabrycky 2011). When applied to humans, however, this approach can become problematic (Sanders & McCormick 1993). Subjective assessments are typically required to evaluate human performance, and human behavior can vary considerably over time. As will be discussed in the following chapters, assessing how humans interact with technology requires a change in the way we think about humans and technology components in complex systems.

C. POTENTIAL SUCCESS FACTORS FOR THE HSI FRAMEWORK

The TRL scale's many attractive qualities have made it the "coin of the realm" for systems assessment (Mankins, 2009). As suggested by the limitations identified with HRL and SHARE, however, a different vehicle is required for assessing human–technology integration. The following attributes are suggested as criteria for a meaningful HSI assessment framework:

1. Simple and Discipline Independent

The HSI framework must be easily understood. Simple, discipline-independent language will increase the framework's acceptance, implementation, and application across disciplines.

2. Surpassing Risk-Based Measures

Measuring the contribution of HSI must go beyond risk-based approaches to encompass all effects on total system performance. Considering risk alone may not offer the breadth required for a complete assessment of HSI performance.

3. Performance Focused

The HSI framework must focus on evaluating the adequacy of the human–technology integration, measured in terms of total system performance. This criterion is a departure from previous approaches, which focus largely on process completion rather than performance outcomes.

By incorporating the helpful qualities of the TRL scale and building upon the useful aspects of HRL and SHARE, a more comprehensive framework for human–technology integration can be envisioned. The following chapters explore these concepts and offer a framework for assessing human-technology integration.

III. CONCEPTUALIZING HSI ACTIVITY DURING SYSTEM ACQUISITION

A. MODEL FOUNDATIONS

This chapter develops a conceptual model for HSI in system acquisition. The model is based on three fundamental tenets: humans and technology are the primary actors in the system; accomplishing system objectives is the raison d'être for the interaction between humans and technology; and, humans and technology have different patterns of emergence during system acquisition.

1. Human and Technology Roles in Modern Military Systems

The allocation of functions to either humans or machines is one of the most important design decisions in HF and HSI. As early as the 1950s, researchers suggested rules of thumb for assigning system tasks to the most capable party. The "Fitts list" (Figure 11), developed by the industrial psychologist Paul Fitts, is perhaps the best known HF design guideline (de Winter & DODou, 2011).

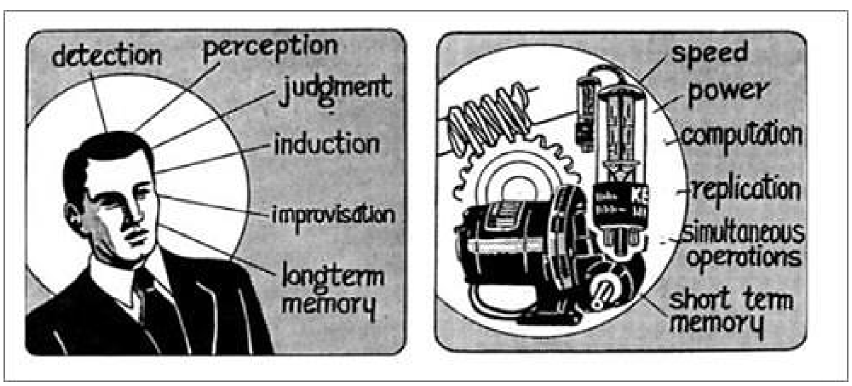


Figure 11. Man and machine capabilities circa 1950 (from de Winter & DODou, 2011)

As technological capability and the understanding of human cognitive processes have improved, the relative strengths and weaknesses of man and technology have been the subject of continual debate (de Winter & DODou,

2011; Dekker & Woods, 2002). In this thesis, the respective merits of humans and technology and their ideal confluence are set aside. What we gather from more than five decades of discourse is that the primary actors in the system are either people or technology (Blanchard & Fabrycky, 2011). Following this logic, functions that cannot be performed by one party must be carried out by the other as they work in tandem to accomplish system goals.

2. Combining Humans and Technology to Accomplish System Goals

In modern systems, the humans, technological tools, and system goals are inextricably linked (Kuuti, 1996; Shattuck & Miller, 2006). This relationship is the focus of activity theory (AT), originating from Soviet psychology in the 1970s. Activity theory asserts that to develop a meaningful understanding of human–technological activity, we must examine three fundamental aspects of interaction (Kuuti, 1996):

- <u>Subject</u>: the user or user group, including operators, maintainers, and supporters
- <u>Tools</u>: technological elements and artifacts used to accomplish system tasks
- <u>Object</u>: the objective or goal of system activity

By considering the interaction of all three elements, AT provides a basic framework for analysis (for a more nuanced discussion of AT, see Kuuti, 1996 or Kaptelinin & Nardi, 1996).

AT is a foundational concept in user experience design and human–computer interaction, where it has informed the merging of humans and technology for more than two decades (Kuuti, 1996). We propose that AT offers similar utility within military acquisition. In system acquisition, requirements derived from broad system objectives guide system development, shaping the ways in which technology and users are integrated. This maps well to the theoretical elements proposed in AT: the “subject” is analogous to the system users, including operators maintainers, and supporters; “tools” are analogous to

the elements operated by users; and the “object” is the performance objectives of the total system. Figure 12 displays this relationship.

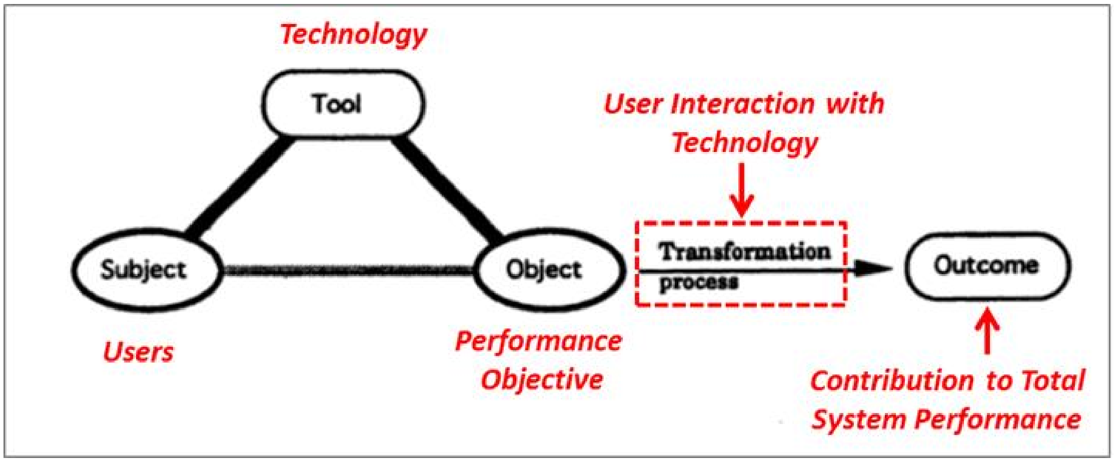


Figure 12. Activity theory (AT) in military acquisition (after Kuuti, 1996)

The transformation in Figure 12 depicts the interaction of subject and tool within the context of the object (the performance objective) to produce an outcome. In the acquisition of a military system, this transformation occurs as users interact with system technology to perform functions. This process captures the essence of HSI. Thus Figure 12 depicts the total system performance that results from human–technology interaction.

B. A MODEL FOR HSI IN ACTION

Bringing together the concepts above, a consolidated view of HSI in military systems acquisition is derived. HSI is represented as the merging of human and non-human elements, unified by system objectives.

1. The Proposed HSI Activity Model

The foundational concepts presented in this research can be unified into a conceptual model. As depicted in Figure 13, the human and technological elements of a system derive from separate origins and merge to accomplish

system objectives. The accomplishment of these objectives is measured by total system performance goals (at right).

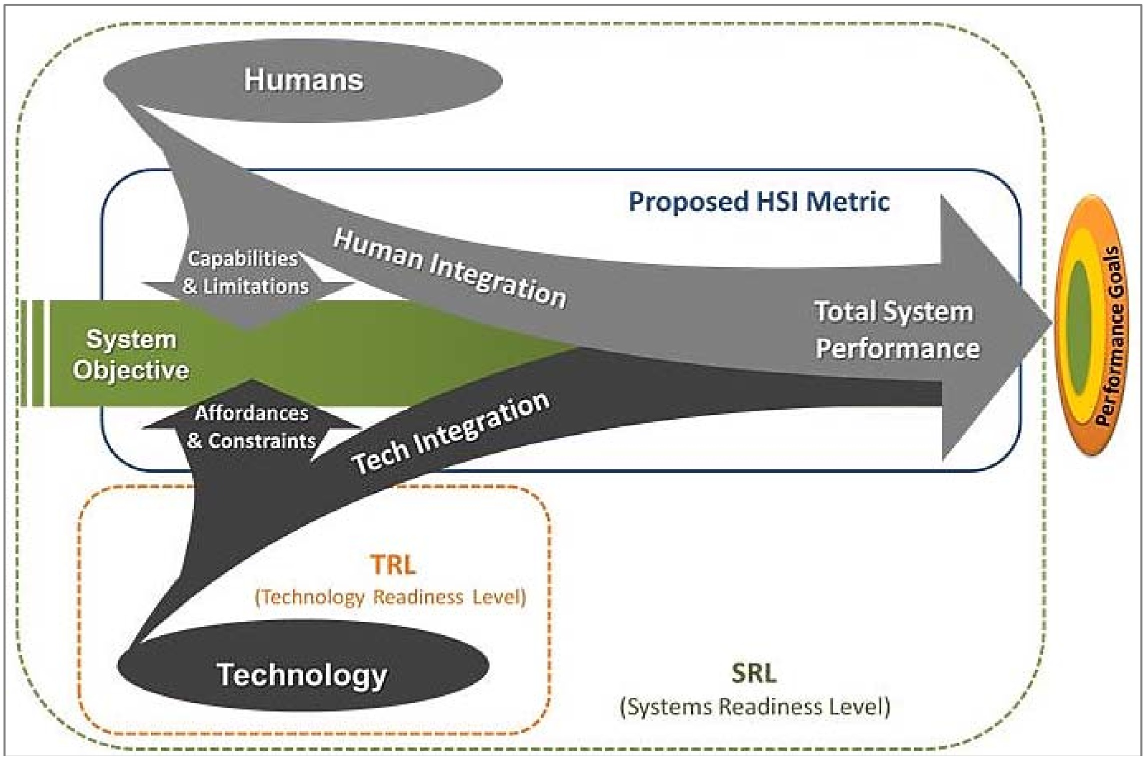


Figure 13. Proposed HSI Activity Model

The system evolves throughout the SE process, as suggested by the movement from left to right in Figure 13. Technology matures over time as an acquisition proceeds. Humans "come as they are," with preexisting capabilities and limitations. What technology permits (affordances) and what it does not allow (constraints), must align with both what a human can do (capabilities) and cannot do (limitations). Human and technological elements interact as the system takes shape, represented by the convergence of arrows in the model. Orange, green, and blue boundaries enclose the respective system assessment areas.

2. Human and Technological Contributions to the System

As defined by Norman, affordances are those fundamental characteristics that determine how a "thing" can possibly be used (Norman, 1988). We use the

term *technology affordances* to capture the ways in which technological elements can be used to perform system functions. For example, steering wheels afford turning, which creates mechanical leverage and controls movement. However, technologies also have needs relative to a system. The steering process requires human perception, strength, judgment, and other capabilities to perform its function. We define these external requirements as technology constraints. These affordances and constraints are revealed as a technology is introduced into system to supplement human capabilities and overcome limitations.

Like technology, humans offer capabilities that can be used in system tasks such as physical strength, vision, audition, memory, and motor skills. Humans also have needs relative to a system, such as a breathable atmosphere, lighting, and protection from mechanical shock, vibration, and excessive gravitational forces (NASA, 2010). Man and machine alike have something they offer and something they need. Table 2 provides examples of this interdependency from the human side, at different levels of task complexity.

Example Human Capabilities	Example Human Needs	Human Function Level	Activity Theory Level
Situation analysis; complex decision making; sense-making; option generation	Decision support, contextualized sensor information; process control	Job Operation	Activity Level
Situation awareness, decision making automation oversight, meta-system monitoring	Control feedback; temporal indicators, system status, spatial orientation, mode awareness	Duty	Action Level
Subsystem monitoring, rule interpretation, system calibration	Sensory input (haptic, visual, auditory etc.); physical functionality, menu control	Task	
Visual scanning, target association, parameter monitoring	Physical access; physical accommodation; visual access	Subtask	Operation Level

Table 2. Human capabilities and limitations
(after Shattuck & Miller, 2006; Blanchard & Fabrycky, 2011; Nardi & Kutti, 1996)

3. Different Paths of Emergence during System Acquisition

Human performance is essential to modern military systems (Booher, 2003). Like measures of propulsion, mechanical strength, and computing power, measures of human physiological, sensory and cognitive characteristics are fundamental considerations for effective design (Miller et. al., 2003). The development of the FIM-92 “Stinger” man-portable air defense system offers a superb example. In the final stages of testing, the fully assembled system (sensors, targeting system, launcher, missile, etc.) was reported to have a kill probability of 60 percent. With a human operator included in the system, however, the actual probability of kill fell to 30 percent (Booher, 2003). Poor human–technology interfaces led to a significant decrement in performance. The lesson for system design is clear: humans and technology must both be considered as contributors to system performance (Booher, 2003).

The FIM-92 example underscores a critical fact about humans and technology. Technology and technology capacity can be evolved relatively quickly over a period of months or years to meet system needs. Human capabilities, however, evolve at a much slower rate over millennia.

Consider the human attributes relevant to a Coast Guard coxswain piloting a small boat. The coxswain’s muscular strength and anthropometric measurements are essential considerations for the tasks at hand such as steering, throttle adjustment, and control actuation. These physical attributes can be measured directly and objectively, and their underlying mechanisms are relatively well understood (NASA, 2010; Pheasant & Haslegrave, 2005). Alternatively, consider the attention capacity and situational awareness of the same coxswain. These attributes may be measured only indirectly (Miller, Crowson & Narkevicius, 2003; NASA 2010) and their underlying cognitive mechanisms are the subject of ongoing scientific study (Shattuck & Miller, 2006).

By virtue of these diverse capabilities, HSI must encompass a wide variety of measures, each with computational limitations. HSI measures range from

nominal and ordinal, which have certain computational restrictions, to interval and ratio measures that allow added statistical precision (Stangor, 2010). Examples of different types of measures relevant to HSI are illustrated in Table 3.

Scale	Definition	HSI/Acquisition Example
Nominal	A categorical variable; offers categorization but cannot be ranked	Gender, ethnicity, operational specialty code, decision making variables, etc.
Ordinal	A qualitative variable with values that can be rank ordered; distance between values is not specified	Operator usability rating, perceived level of difficulty, perceived operator fatigue, situation awareness score, color coding, etc.
Interval	Variable where differences in values reflect distance between the values; zero point is arbitrary	Temperature, seating orientation (degrees), direction of airflow, operator intelligence quotient, etc.
Ratio	Variable with defined ratio values and a true zero point	Pounds of force required, button relief, processing speed, luminance, etc.

Table 3. Measurement theory for military HSI
(after Stangor, 2010)

Although the capabilities and limitations of individual persons vary widely, they do so within a relatively consistent range. Intelligence quotient, visual acuity, or grip strength, for example, vary widely among individuals yet fall within a predictable range across populations (Chapanis, 1996; Miller et. al., 2003). Technology, by contrast, can be constructed from the ground up with attributes chosen to fulfill a specific purpose. The materials, types of technology, and underlying architecture of a system can be re-composed as needed (Blanchard & Fabrycky, 2011). Humans are far more constrained as a system variable. Human performance variability can be reduced to some extent through selection, training, and manipulation of factors affecting human states. Unlike technology, however, recomposing or re-engineering human capabilities is simply not a viable system design option.

Humans and technology develop from different origins, and contribute to system functions in very different ways. For this reason, our model of HSI Activity incorporates separate pathways for Humans and Technology. Put simply, technology may or may not be ready for the systems we desire, but humans are

ready now. It is the responsibility of those who design the system to do so in a manner that provides the affordances and constraints that align with the capabilities and limitations of the humans who will operate, maintain and support the system.

4. Advantages of the Proposed HSI Activity Model

The proposed HSI activity model adds to existing HSI and HF models by portraying the core activity of HSI as a single figure (for more on founding HSI models, see Booher, 2003). This feature is essential for improving HSI understanding and awareness, as advocated in earlier chapters. The HSI activity model lays the groundwork for the HSI assessment framework proposed in Chapter IV.

The HSI activity model doubles as a design paradigm. Adopting the view proposed in the model, technology affordances are considered in concert with their constraints, and human capabilities are considered in concert with the limitations they bring. This provides valuable perspective for design before the integration of user and technology is attempted.

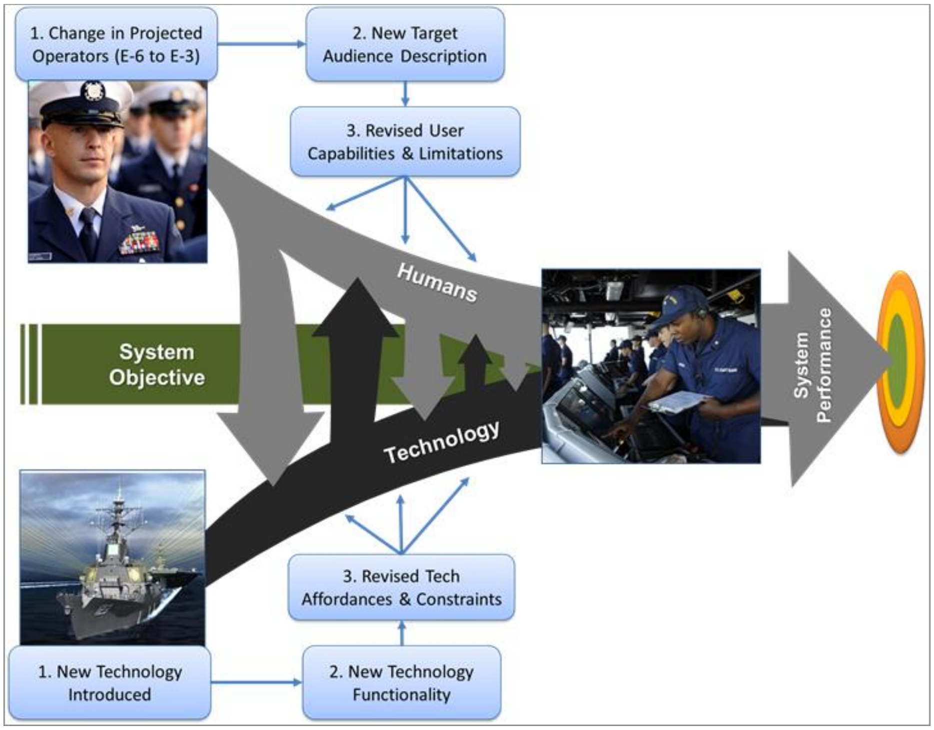


Figure 14. HSI Activity Model example application

Figure 14 illustrates an application of the HSI activity model. Human capabilities and limitations are integrated progressively with technology affordances and constraints. First, human capabilities and limitations emerge, based on the selection of users (top left). As the human contribution emerges, technology is introduced, offering new functionality but also creating new demands on users (bottom center). The contributions and needs of both are integrated to achieve system performance goals (right).

5. Limitations of the HSI Activity Model

Military acquisition often includes the iterative introduction of new technologies over multiple years of system development. In addition, user groups (operators, maintainers, and supporters) may be recomposed to meet changing program needs. It is conceded that the updating of human and technological needs will probably not occur in the progressive, neatly discernable fashion depicted by the alternating gray arrows in Figure 14.

Like other HF models, the proposed HSI activity model is an abstraction of a complex and multifaceted process; the model has the virtue of simplifying and generalizing HSI activities so they can be readily understood (Norman, 1988; Parasuraman, Sheridan, & Wickens, 2000). The inherent tradeoff with this abstraction is that precise measures have limited applicability. This oversimplification is made with a deliberate purpose: increasing HSI understanding and awareness. The equally important task of measuring HSI will be explored in the next chapter.

IV. DEVELOPMENT OF A FRAMEWORK FOR ASSESSING HSI DURING SYSTEM ACQUISITION

This chapter documents the creation of a framework for assessing HSI in system acquisition. The framework was created in consultation with NPS HSI faculty and refined with HSI practitioners from the Coast Guard Human Systems Integration Division (CG-1B3) during a series of workshops. As a culminating exercise, practitioners applied the framework to assess a current acquisition program, the U.S. Coast Guard Fast Response Cutter, during a mock design review. The resulting Comprehensive Human Integration Evaluation Framework (CHIEF) elements are presented at the conclusion of the chapter.

A. STEP ONE: DEVELOPING AN HSI FIGURE OF MERIT

A “figure of merit” (FOM) is used in engineering to develop a concise expression of the "degree of goodness" among competing alternatives during design (Lee, 2011). Developing a FOM allows engineers to establish a value hierarchy and evaluate design alternatives based on their relative merit in a particular design application. According to veteran employees at NASA, the TRL scale was constructed specifically as a FOM (Mankins, 2009). Early in this project, we decided to develop a full FOM for HSI.

First, a value hierarchy was created for each HSI domain. The objective of this effort was to create a generalized, system-independent definition of HSI success and failure for each HSI domain. As a benchmark for success, HSI FOM language was developed to match the concise language employed by the NASA/DOD TRL scale. Statements describing the desired state and undesired state of each HSI domain were crafted. Concepts and language were synthesized from the Coast Guard Major Systems Acquisition Manual (MSAM), the Defense Acquisition Guidebook (DAG), the U.S. Air Force Human Systems Integration Handbook, the U.S. Army MANPRINT Handbook, and academic textbooks.

Developing TRL-like definitions for each HSI domain required a significant reduction in verbiage. This was achieved by removing overly specific phrases, context, and design instances from main definitions, and describing them separately as design considerations. Table 4 shows the resulting HSI FOM for the domains of personnel, manpower and PS&T.

Domain	Manpower	Personnel	Performance Support & Training
Desired State	The correct number and mix of personnel required for system operation, maintenance and support is identified; manning reflects the full range of operations, work demands, operating conditions and deployment scheme for the system.	Human performance factors are identified and matched to system tasks and workload; criteria are developed to effectively recruit, select and train personnel for safe, efficient and effective system operation.	Competency requirements are established to reflect end-user tasks and workload; knowledge, skill and ability gaps are appropriately identified and training system is developed to match end-user learning needs.
Design Concerns	*manpower estimates, individual competencies, team competencies, occupational specialties, resilience, task capacity, net workload, watch schedules, operating conditions, ship fill, deployment schedules, chronic fatigue levels*	*Target audience descriptors, knowledge, skills, aptitudes, experiences, traits, cognitive abilities, cognitive style, personality factors; workload, cognitive demands, task requirements, task duration, task frequency, task design, task environment, operating conditions*	*Knowledge, skills, aptitudes, experiences, cognitive abilities, cognitive style, personality factors; competencies, task demands, cognitive demands, subject matter, audience, learning styles, delivery mode, training infrastructure, instructional technology, instructional design, evaluation metrics*
Undesired State	The mix and/or number of personnel specified for the system exceeds allowable manning levels; manning is insufficient for the full range of operations, work demands, operating conditions and deployment scheme of the system.	Individual performance factors are poorly matched to system tasks, workload and skill requirements. Criteria are not adequately established or implemented for recruiting, selecting, training and retaining personnel that meet or exceed the required aptitudes and traits for the system.	Competency requirements are not matched with end-user tasks and workload; knowledge and skills gaps are inadequately understood or defined; training system is incompatible with end-users learning needs and environment; delivery and retention of job-relevant knowledge, skills and abilities is inadequate.
References	DAG Chapter 6.3 AF HSI Handbook MANPRINT Handbook CG MSAM	DAG Chapter 6.3 AF HSI Handbook MANPRINT Handbook CG MSAM	DAG Chapter 6.3 AF HSI Handbook MANPRINT Handbook CG MSAM

Table 4. Figure of merit for three HSI domains

The full HSI FOM including statements for all Coast Guard HSI domains, is included in Appendix A. As seen in the appendices, outcomes in each HSI domain were successfully categorized using the FOM approach. This process revealed that a key element of NASA TRL could be applied to assessing HSI: that is, succinct, generalizable desired states could be articulated in a way similar to TRL definitions. The simple, discipline-independent language desired for the HSI Framework was now available.

1. Centering the Scale: Balancing Technology and Human Needs for Total System Performance

Developing the HSI FOM required identification of desired and undesired states in each HSI domain. As a result of this process, the central theme presented in the HSI Activity Model was confirmed: optimal performance in each HSI domain was best described as the balancing of needs between humans and technology for the accomplishment of system goals. This was an important confirmation of the activity-based view of HSI presented in the last chapter.

The manpower domain offered an interesting case study. Manpower activities in acquisition typically focus on crafting the correct mixture of personnel and positions to meet system performance needs. This typically entails matching the competencies and capacity of personnel to the work presented by the system (Defense Acquisitions University, 2010). Developing a FOM for this activity involved a critical question: For a particular system, what characteristics make a given manpower solution more or less desirable than another?

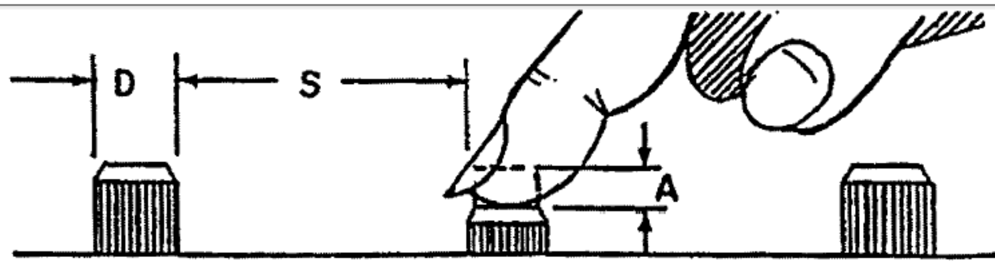
In an era of diminishing budgets, cost typically anchors our assessment of acquisition alternatives. The preferred solution offers the desired system performance attributes at a given cost level. Thus, establishing a preferred manpower alternative requires that we establish the candidate that will lead to the best possible total system performance (Barber, 2011; Defense Acquisitions University, 2010). By examining the dynamic interplay between the capabilities

and limitations of humans and the affordances and constraints of technology, we can identify the most viable manpower alternatives.

2. Assembling HSI Understanding: From Detailed Standards to Management Indicators

Measuring HSI efficacy is a particularly challenging endeavor. The single domain of HFE alone requires diverse policies, standards and design criteria. The Department of Defense Design Criteria Standard–Human Engineering (MIL-STD-1472G) is evidence of this fact, with detailed standards governing every aspect of human-technology interaction across the full spectrum of military systems and environments. NASA's Human Integration Design Handbook (NASA/SP-2010–3407) offers similarly comprehensive guidance, with more than 1,000 pages of detailed standards.

Despite their extraordinary level of detail and breadth, interpreting and applying these standards can be challenging (Chapanis, 1996; Lockett & Powers, 2003). Consider the example of designing a single button for a control console. More than ten design parameters for the configuration of the button can be found in MIL-STD-1472G. Example parameters include button relief (depth of press), spacing, size, shape, resistance (force required for actuation), arrangement in relation to function, labeling, luminance (ambient light), lighting (button illumination), reflectivity and guarding. Figure 15 offers a sampling of these standards.



	Dimensions (D, Diameter)						Resistance		
	Fingertip		Thumb		Palm				
	Bare hand	Gloved hand [1/]	Bare hand	Gloved hand [1/]	Bare hand	Gloved hand [1/]	Single finger	Different fingers [2/]	Thumb/palm
Minimum	10 mm (0.4 in)	19 mm (0.75 in)	19 mm (0.75 in)	25 mm (1.0 in)	40 mm (1.6 in)	50 mm (2.0 in)	2.8 N (10 oz)	1.4 N (5 oz)	2.8 N (10 oz)
Maximum	25 mm (1.0 in)	--	25 mm (1.0 in)	--	70 mm (2.8 in)	--	11.0 N (40 oz)	5.6 N (20 oz)	23.0 N (80 oz)

	Displacement (A)	
	Fingertip	Thumb or palm
Minimum	2.0 mm (0.08 in)	3.0 mm (0.12 in)
Maximum	6.0 mm (0.25 in)	38 mm (1.5 in)

	Separation (S)				
	Single finger		Single finger sequential [3/]	Different finger [3/]	Thumb or palm [3/]
	Bare	Gloved			
Minimum	13 mm (0.5 in)	25 mm (1.0 in)	6.0 mm (0.25 in)	6.0 mm (0.25 in)	25 mm (1.0 in)
Preferred	50 mm (2.0 in)	--	13 mm (0.5 in)	13 mm (0.5 in)	150 mm (6.0 in)

Figure 15. Button configuration parameters (from MILSTD 1472-G)

Detailed HSI and HFE standards offer essential guidelines for human–technology interface design. For their effective application, however, additional factors must be taken into account. In practice, system performance is shaped by user characteristics and the circumstances of the task (Chapanis, 1996; Kuuti, 1996). To evaluate the efficacy of a human-technology interface design, we must extend our analysis to include other aspects of the task activity.

Our discussion in Chapter III advocated an activity-based evaluation of HSI. To carry this out, we require specific measures: HSI tools, techniques, approaches, and methods (TTAMs) that capture the interaction of configured system technology with representative user characteristics, in a relevant work context. For brevity, we refer to these as aggregating measures.

A survey of HSI literature reveals a host of TTAMs suitable for use as aggregating measures (UK MoD, 2008; FAA, 2014). Dynamic anthropometric modeling (DAM) is an example within the HFE domain, as seen in Figure 6 of Chapter I. Simulated human users and configured technology are placed into a virtual prototype through computer modeling; the practitioner can then evaluate technology features, such as buttons or control configuration, in concert with relevant user characteristics, such as anthropometric measures or range of motion (Pheasant & Haslegrave, 2005). Practitioners can then assess human–technology interaction outcomes for the system.

Virtual or physical prototyping provides a convenient example of an aggregating measure in HFE; however, suitable measures in other domains are also available. The fatigue avoidance scheduling tool (FAST), for instance, serves as an aggregating measure for the manpower domain. FAST uses the 72-hour sleep history of individuals to predict their alertness in tasks that require vigilance (Eddy & Hursh, 2006). Manning levels can then be adjusted to ensure that the individuals performing the task are capable of the vigilance required.

Once sufficient evidence of HSI outcomes is established for the selected HSI domain, the impact of human–technology interaction on total system performance can be assessed. Figure 16 illustrates an example of this measurement process for the HFE domain. HFE policies and standards form the basis for engineer and practitioner activity; system attributes are expected to be developed based on these standards. The users are evaluated as they interact with the system in the work context, using aggregating measures. These measures are then combined to formulate an assessment of the HFE domain in question, Evaluations of the other HSI domains are combined into a comprehensive HSI assessment, using the framework proposed later in this chapter.

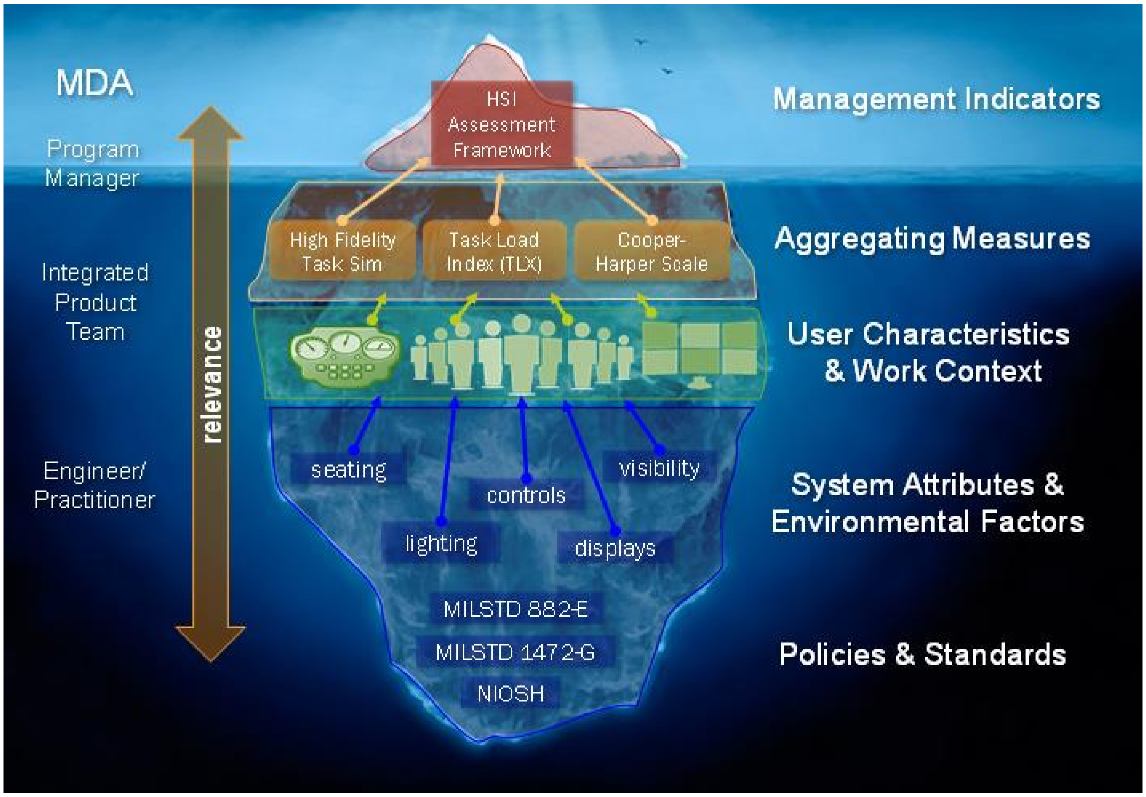


Figure 16. The “Iceberg”: From HFE standards to HSI performance

Our study of technology readiness assessment in Chapter II revealed a key lesson: system assessment measures must be suitable for a broad audience. We propose that this is equally true for assessing HSI. Acquisition program personnel often have limited exposure to the HSI discipline. Despite this, modern acquisition requires program managers, systems engineers, contracting specialists and others to acquire and apply some basic HSI knowledge. The proposed HSI evaluation framework aims to augment acquisition practitioner knowledge by offering a consolidated assessment of HSI that is rooted in quantitative data and empirically derived standards.

B. STEP TWO: DEVELOPING A HUMAN INTEGRATION EVALUATION FRAMEWORK

With the HSI FOM and measurement approach established, attention shifted to development of an assessment format. Assembling HSI information across multiple domains presented a challenge. A familiar HFE assessment tool

provided an analog to meet this challenge and inspired the initial format for the HSI Framework.

1. Establishing a Format for HSI Assessment

Assessment of HSI required a novel approach. Aggregating measures had to be consolidated across seven HSI domains and then presented in an integrated and understandable manner. A variety of HF and HSI frameworks, tools, and evaluation schemes were analyzed, including those discussed in Chapter II. The NASA task-load index (TLX) scale presented several interesting qualities pertinent to the task of assessing HSI. TLX was developed by NASA in the 1980s for assessing human workload in human–technology systems (Hart & Staveland, 1988). NASA's current version of the scale is shown in Figure 17.

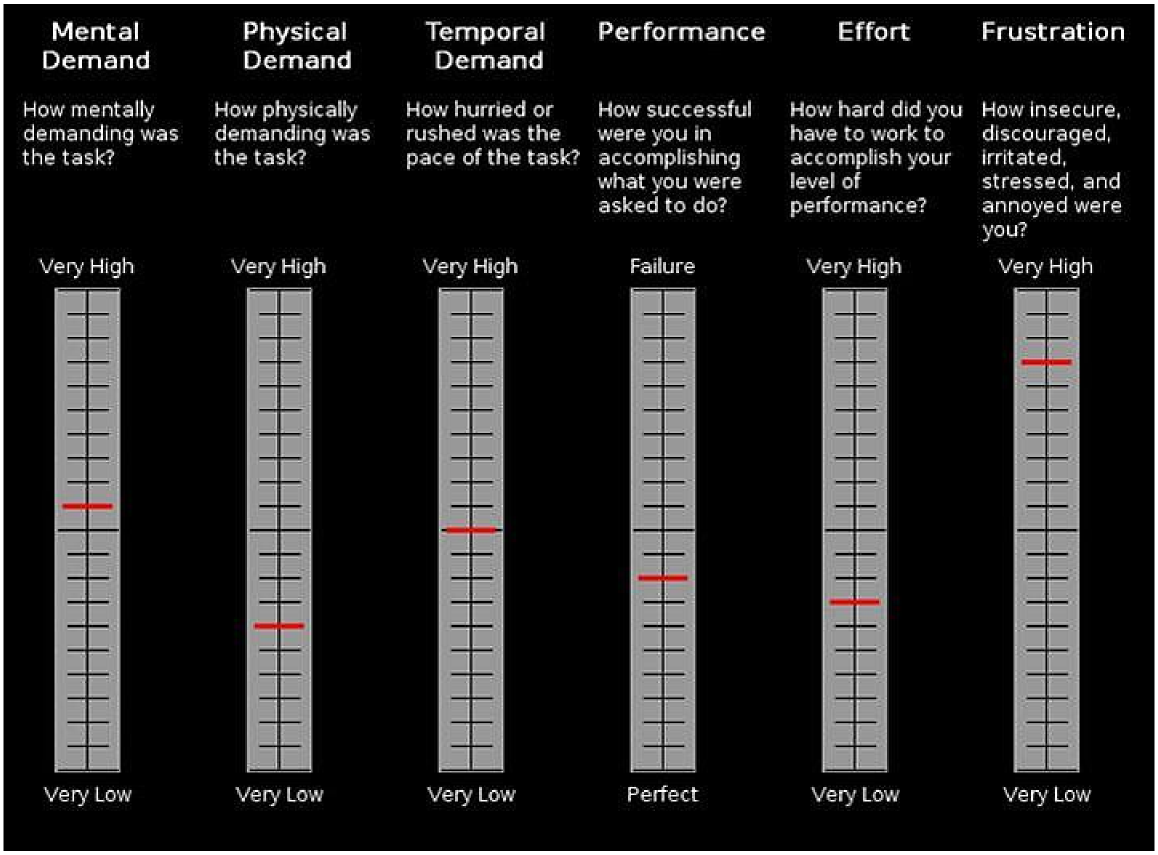


Figure 17. NASA TLX scale (electronic version) (from Wikipedia commons, 2012)

The TLX scale assesses multiple task dimensions within a given context. Similarly, the goal of an HSI assessment is to capture the contributions of each HSI domain and assess their contribution relative to total system performance. The NASA TLX scale demonstrated that this type of multi-dimension evaluation could be applied successfully (Hart, 2006). This provided the inspiration for the initial HSI assessment framework.

2. Development of an Initial HSI Assessment Framework

As a first step toward constructing an evaluation framework, desired end states for each HSI domain were adopted from the HSI FOM. Definitions were crafted to focus the assessment of each HSI domain, similar to the questions provided for NASA TLX performance dimensions. Initial HSI domain definitions appear in Figure 20.

The initial HSI framework borrowed heavily from the format and orientation of NASA TLX. Initial blackboard prototypes were evolved into a spreadsheet-based framework, as seen in Figure 18. HSI domain definitions were listed across the top of the matrix, with rating scales in the columns beneath each domain. A data field was provided beneath each domain definition for practitioners to list aggregating measures and results.

Next, a qualitative, five-level rating scale was added to capture the contribution of each domain to overall system performance. This “total system performance implication” (TSPI) rates the extent to which the integration of human operators, maintainers, and supporters into the system enhances or degrades the total performance. The TSPI scale operationalized HSI performance into five categories (from worst to best): severe degradation, moderate degradation, borderline to mild degradation, enhancement, and optimizing, as seen in Figure 18.

Comprehensive Human Integration Evaluation Framework (CHIEF) DRAFT		Manpower	Personnel	Performance Support & Training	Human Factors Engineering
		The mixture of required positions is balanced for the system's aggregated human workload, and users are within acceptable limits of endurance, fatigue, and skills.	Criteria are sufficiently established to identify, train and retain personnel capable of performing at or above the levels required by the system, within projected manpower limitations.	The instructional system design develops and delivers the human performance needed for efficient, effective and safe system operation within manpower, personnel and system constraints.	The system design optimizes the capabilities and limitations of human operators, maintainers, and support personnel for efficient, effective, suitable, and safe system performance.
		Aggregating Measures			
Total System Performance Implication					
Optimizing	5				
Enhancement	4				
Borderline to Mild Degradation	3				
Moderate Degradation	2				
Severe Degradation	1				

Figure 18. Initial HSI framework (four domains)

Criteria were developed to assist practitioners in assigning a total system performance implication rating based on the aggregating measures for each domain. To identify language capable of distinguishing performance within and across multiple HSI domains, an in-depth review of HSI standards and policies was conducted. Criteria were synthesized from a wide variety of standards including MILSTD 1472-G, NASA STD-3000, the Air Force HSI Handbook, and the U.S. Army MANPRINT Handbook. Potential evaluation categories were developed based on their ability to apply across HSI domains. The initial categories were identified as human–technology balance factor, human risk factor, and weight of contributing evidence. These categories and their rating criteria are shown in Table 5.

	Balancing of Human & Technological Needs	Human Risk Factor	Weight of Contributing Evidence
5	**Very Good.** The limitations of human users are fully understood and accounted for across the system for the given domain; application of technology is tailored for optimal leveraging of human capabilities to fulfill technology constraints.	**Completely Acceptable.** The system places humans users are well within acceptable limits for health, safety and welfare for the given domain; task design, work design,	**Validated as Positive.** Domain performance meets or exceeds minimum thresholds, benchmarks and standards confirmed across the spectrum of end users, operating modes and conditions, in relevant environments.
4	**Good.** The limitations of human users are understood and accounted for in system design for the given domain; application of technology is tailored for effective use of human capabilities to fulfill technology constraints.	**Reasonably Acceptable.** The system places humans within acceptable limits for health, safety and welfare; human functions, work design and work schedule contribute to effective and efficient and safe system performance.	**Verified as Positive.** Domain performance meets or is predicted to meet minimum thresholds, benchmarks and standards, verified by prototype testing, high fidelity simulation, or similarly reliable means.
3	**Borderline.** The limitations of human users are not fully accounted for in the system design; the application of technology fails to leverage available human capabilities–or- borders on exceeding human capabilities.	**Borderline.** The system places humans narrowly or partially within acceptable limits for health, safety and welfare, with occasional excursions from safe limits or safe work practices.	**Inconclusive.** Domain performance may or may not meet applicable thresholds, benchmarks and standards; information derived from testing or simulation is *not available* -or- is *inadequate* to confirm compliance.
2	**Poor.** Human capabilities and limitations are poorly matched to system aggregated tasks and workload; technology unnecessarily impedes, impairs or poorly human capabilities with technology constraints.	**Unacceptable.** The system places humans routinely placed outside of acceptable limits for health, safety and welfare for the given domain; major contribution to program risk.	**Verified as Negative.** Domain performance thresholds, benchmarks and standards are not met -or- domain performance thresholds, benchmarks and standards are undefined, and therefore untested.
1	**Very Poor.** Human capabilities and limitations are very poorly accounted for in the system design; the application of technology unnecessarily and unacceptably impairs human capabilities to fulfill technology constraints.	**Extremely Unacceptable.** The system routinely places humans outside of acceptable limits for health, safety and welfare for the given domain; high potential exists for mishap, injury or death.	**Validated as Negative.** Domain performance has tested below threshold levels, as confirmed with actual system users in prototypes or in high fidelity simulation.

Table 5. Initial HSI framework rating scale criteria

The content and compatibility of scales across HSI domains were a subject of continuous discussion and refinement during the early HSI Framework development. This initial HSI Framework and rating scale established a starting

point. Further refinement of the framework required feedback from current HSI practitioners, as described in the next section.

C. STEP THREE: REFINING THE FRAMEWORK WITH HSI PRACTITIONERS

The initial CHIEF rating approach was refined during a series of four workshops with experienced HSI practitioners from the U.S. Coast Guard Human Systems Integration Division (CG-1B3). The panel consisted of six active-duty and civilian HSI personnel assigned to CG-1B3. Panel members represented all HSI domains and ranged in experience from O-4 to O-5 (military), and GS-12 to GS-14 (civilian). Practitioners participated remotely from CG-1B3 offices located at U.S. Coast Guard Headquarters in Washington, DC. Participation was strictly voluntary, and interaction was documented on a non-attribution basis. The workshop plan was reviewed by the NPS Institutional Research Board (IRB) and was determined not to be human subject research. However, the workshop participants were accorded the rights and privileges to which they would have been entitled had it been deemed human subjects research.

The four workshops were hosted by NPS via virtual meeting software over a period of ten weeks. Participants were invited to join a virtual collaboration worksite where workshop presentation material, references, and participant uploads were made accessible. Sessions were jointly moderated by the author and NPS HSI faculty members. Workshops were scheduled according to CG-1B3 personnel availability and averaged approximately two hours in length. A screenshot of the workshop collaboration site and presentation materials for all workshops is contained in the appendices.

1. Workshop One: Introduction and Framework Refinement

The first workshop introduced participants to the research, processes, and products developed for this thesis. Six participants were in attendance and seven HSI domains were represented. Ground rules, objectives, and activities for the workshop series were presented for discussion. An overview of the HSI Activity

Model and the initial HSI Framework were presented, followed by a question and answer session.

After the opening presentation, draft HSI domain definitions (Figure 18) were presented. Workshop participants were prompted with a scenario in which a senior acquisitions official had requested an abbreviated definition of their particular HSI domain, containing no jargon or buzzwords. Practitioners were then asked to refine the draft HSI domain definitions.

A thirty-minute breakout session was conducted, during which the practitioners revised the initial HSI domain definitions. The revised definitions were submitted electronically and then presented to the group. The workshop concluded after consensus had been achieved and plans for a second workshop were discussed. The finalized HSI domain definitions appear in Figure 19.

Manpower	*The mixture of required positions is balanced for the system's aggregated human workload, and users are within acceptable limits of endurance, fatigue, and skills.*
Personnel	*Criteria are sufficiently established to identify, train and retain personnel capable of performing at or above the levels required by the system, within projected manpower limitations.*
Performance Support & Training	*The instructional system design develops and delivers the human performance needed for efficient, effective and safe system operation within manpower, personnel and system constraints.*
Human Factors Engineering	*The system design optimizes the capabilities and limitations of human operators, maintainers, and support personnel for efficient, effective, suitable, and safe system performance.*
Systems Safety & Occupational Health	*The system safeguards human users and equipment from acute and chronic hazards to health and safety to enable efficient, effective and safe system performance.*
Survivability	*The system safeguards human users from hazards, and provides efficient and effective means for emergency egress and escape.*
Habitability	*The system configuration and environment features support effective human performance by providing for the comfort, convenience, and quality of life of personnel.*

Figure 19. Finalized HSI domain definitions

2. Workshop Two: Refinement of Rating Scale Criteria

Workshop Two focused on refining the rating scale criteria for the HSI Framework. Four of the Workshop One practitioners were in attendance, and six HSI domains were represented. The draft framework, proposed measurement approach (Figure 16), a proposed workflow, and the draft rating scale criteria were presented, followed by an extensive question and answer session. Practitioner input focused on the perceived strengths and weakness of the aforementioned materials based on their experience.

Practitioners identified three central concerns stemming from the initial HSI Framework. First, the use of a five-level rating scale (Table 5) was considered excessive. A main point of contention was that the inclusion of two levels of performance above “acceptable” did not align favorably with current acquisition practices, which are based on objective and threshold values (for additional description of these values, see the Defense Acquisition Guidebook (DAG) 2011, Section 2.1.1). Second, the rating scale criteria (i.e., defined scale levels) were viewed by participants as containing too much detail, inviting overly subjective interpretation. And third, ratings across categories were evaluated as not sufficiently synchronized with the TSPI scale (Figure 18). In particular, practitioners felt that they could not clearly differentiate between acceptable and non-acceptable HSI performance, given the initial rating scale.

Following the opening discussion, practitioners were provided draft rating scales and asked to revise the wording. Practitioners were informed they would be asked to rate a current system acquisition for an upcoming management briefing and to defend their HSI ratings based on the scale criteria. A thirty-minute breakout session was then held for discussion and analysis. The workshop adjourned with a request from the author for continued offline discussions to resolve the concerns raised. Recommended modifications were received from CG-1B3 within several days. Practitioners recommended the following adjustments:

- Rating scales should remain at five levels to avoid skewing the scale toward suboptimal HSI performance levels.

- Use of the terms “threshold” and “objective” should be omitted in favor of more universal, acquisition-independent language.

- Scale wording should be aligned such that the minimum level of acceptability occurs between levels two and three.

- The “Weight of Contributing Evidence” category should be separated from direct rating scales and implemented separately.

The HSI Framework was reformatted and refined based on adjustments requested by the practitioners. Refinements included altering the scale language to harmonize rating categories, removing intermediary scale criteria for simplicity, and isolating and renaming the “Weight of Contributing Evidence” category as the “Acquisition Performance Factor.” It was requested that this factor be added after the domain had been scored. An “Accommodation Factor” category was introduced to supplement the other scales based on its applicability across domains. The reformatted rating scales and criteria are presented in Table 6. The acquisition performance rating scale is presented in Table 7.

	Balancing of Human & Technological Needs	Human Risk Factor	Weight of Contributing Evidence
5	**Very Good.** The limitations of human users are fully understood and accounted for across the system for the given domain; application of technology is tailored for optimal leveraging of human capabilities to fulfill technology constraints.	**Completely Acceptable.** The system places humans users are well within acceptable limits for health, safety and welfare for the given domain; task design, work design,	**Validated as Positive.** Domain performance meets or exceeds minimum thresholds, benchmarks and standards confirmed across the spectrum of end users, operating modes and conditions, in relevant environments.
4	**Good.** The limitations of human users are understood and accounted for in system design for the given domain; application of technology is tailored for effective use of human capabilities to fulfill technology constraints.	**Reasonably Acceptable.** The system places humans within acceptable limits for health, safety and welfare; human functions, work design and work schedule contribute to effective and efficient and safe system performance.	**Verified as Positive.** Domain performance meets or is predicted to meet minimum thresholds, benchmarks and standards, verified by prototype testing, high fidelity simulation, or similarly reliable means.
3	**Borderline.** The limitations of human users are not fully accounted for in the system design; the application of technology fails to leverage available human capabilities–or-borders on exceeding human capabilities.	**Borderline.** The system places humans narrowly or partially within acceptable limits for health, safety and welfare, with occasional excursions from safe limits or safe work practices.	**Inconclusive.** Domain performance may or may not meet applicable thresholds, benchmarks and standards; information derived from testing or simulation is *not available* -or- is *inadequate* to confirm compliance.
2	**Poor.** Human capabilities and limitations are poorly matched to system aggregated tasks and workload; technology unnecessarily impedes, impairs or poorly human capabilities with technology constraints.	**Unacceptable.** The system places humans routinely outside of acceptable limits for health, safety and welfare for the given domain; major contribution to program risk.	**Verified as Negative.** Domain performance thresholds, benchmarks and standards are not met–or–domain performance thresholds, benchmarks and standards are undefined, and therefore untested.
1	**Very Poor.** Human capabilities and limitations are very poorly accounted for in the system design; the application of technology unnecessarily and unacceptably impairs human capabilities to fulfill technology constraints.	**Extremely Unacceptable.** The system routinely places humans outside of acceptable limits for health, safety and welfare for the given domain; high potential exists for mishap, injury or death.	**Validated as Negative.** Domain performance has tested below threshold levels, as confirmed with actual system users in prototypes or in high fidelity simulation.

Table 6. Finalized CHIEF rating scale criteria

Acquisition Progression Factor (specific to each HSI domain)		
Behind The quantity or quality of contributing evidence leading to the domain score is less than expected/required for the current acquisition phase.	**Concurrent** The quantity and quality of contributing evidence is commensurate with the acquisition phase.	**Ahead** The quantity and quality of contributing evidence is more than expected/required for the current acquisition phase.

Table 7. Acquisitions performance factor (APF)

3. Workshop Three: Framework Finalization

Workshop Three was aimed at finalizing the rating-scale criteria and the design of the HSI Framework scoring matrix. Six of the Workshop One practitioners were in attendance, and five HSI domains were represented. Workshop participants were presented with the revised rating scale definitions, including the “Accommodation Factor” category. The reformatted rating criteria met with broad consensus.

Candidate designs of the HSI Framework scoring matrix were then presented. Alternatives included two versions with vertical performance scales (similar to TLX), and one with a horizontal performance scale. Practitioners were asked to select the candidate they considered most effective at conveying HSI assessment results. The horizontal format (Figure 20) was selected by the practitioners.

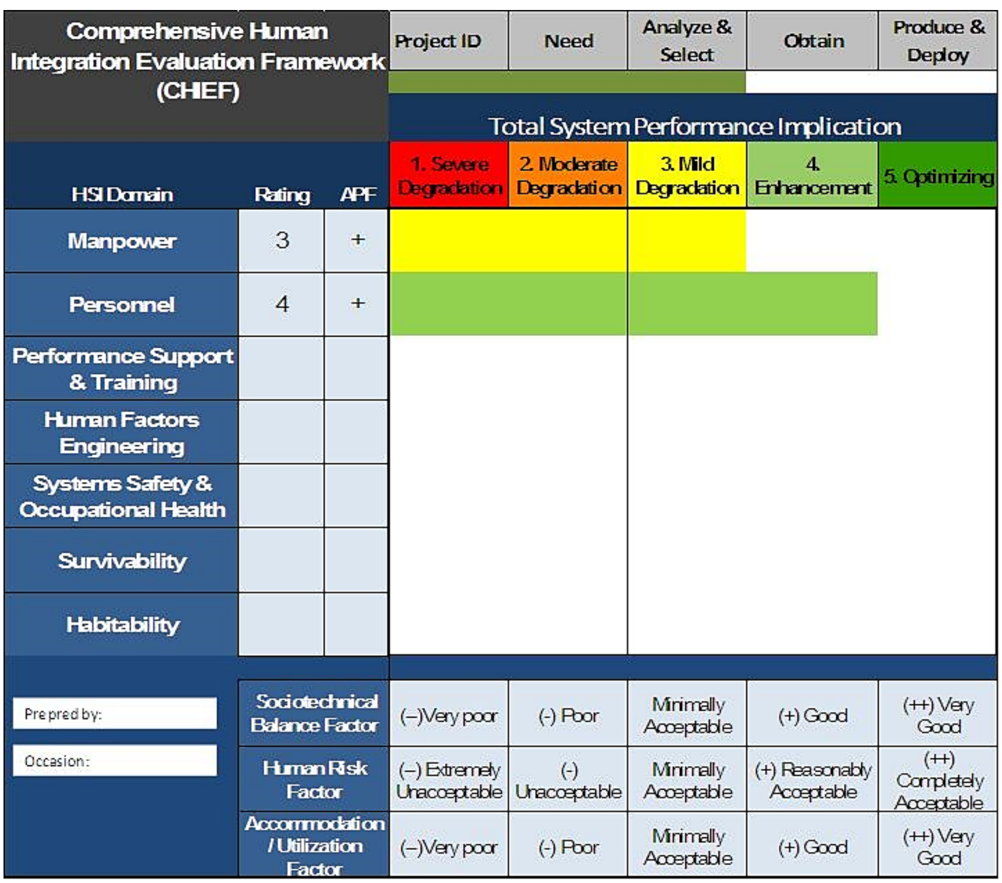


Figure 20. Selected scoring matrix with example ratings

The workshop concluded after the practitioners had nominated a test case that would be used in the final workshop to validate the HSI Framework. Past, current, and future acquisition programs were considered as candidates. A recently fielded system, the Coast Guard Fast Response Cutter (FRC) (Figure 21) was selected for the case study. A poll revealed that all participants had recent work experience within the FRC acquisition. The recently completed Production Readiness Review (PRR) would serve as a scenario for the HSI Framework rating (for more information on the engineering review process, see the DHS Instruction/Guidebook 102–01–001, Appendix B – Systems Engineering Lifecycle).

Figure 21. Coast Guard Fast Response Cutter (FRC) (from U.S. Coast Guard heartland.coastguard.DODlive.mil)

4. Workshop Four: HSI Framework Test Case

Workshop Four employed the HSI Framework to conduct a simulated HSI assessment of the FRC acquisition program prior to the PRR. Four out of the six original practitioners were in attendance, and six HSI domains were represented. The workshop focused on evaluating the usability of the HSI framework and establishing a preferred scoring method.

The workshop began with a briefing on the test scenario. Practitioners were asked to draw on their knowledge of specific HSI measures and test data at the time of the PPR to develop HSI Framework ratings and then present domain scores and justifications to the group. An example workflow for the HSI Framework was presented by the moderators. A thirty-minute breakout session was held to develop ratings for each HSI domain. CG-1B3 leaders compiled individual domain ratings for the FRC. Practitioners then presented justifications for each rating based on the HSI Framework rating scales and criteria.

With HSI Framework domain scores established, the desired method for representing those scores became the focus of the discussion. The merits of various numerical approaches were presented by the domain practitioners and HSI managers. Several key areas were addressed, including the appropriate level of numerical accuracy (i.e., number of decimal places), desired technique for numerical averaging, and the possibility of weighting the domains. The workshop concluded with consensus on the following measurement approach:

- Numerical scoring would be limited to whole numbers, consistent with the level of precision afforded by HSI measures.
- The Acquisition Performance Factor (APF) would be assigned a plus or minus symbol (+/-), in order to indicate the trend of performance in each domain without affecting the numerical score.
- Where possible, a numerical average should be avoided in favor of displaying a complete score across all domains.
- When an average was desired (i.e., representation of all HSI domains scores was not possible), scores falling below the acceptable level should also be indicated.
- The final framework should include the ability to declare selected domains to be not applicable for specific projects.

D. FINAL VERSION OF THE CHIEF

The final version of the HSI Framework assembles all the components refined during the four workshops: the scoring matrix, the finalized domain definitions, and the rating scales with guiding criteria. We refer to these

collectively as the Comprehensive Human Integration Evaluation Framework (or CHIEF) rating system. This rating system can be used to assess HSI efficacy across HSI domains in any system acquisition program (Figure 22).

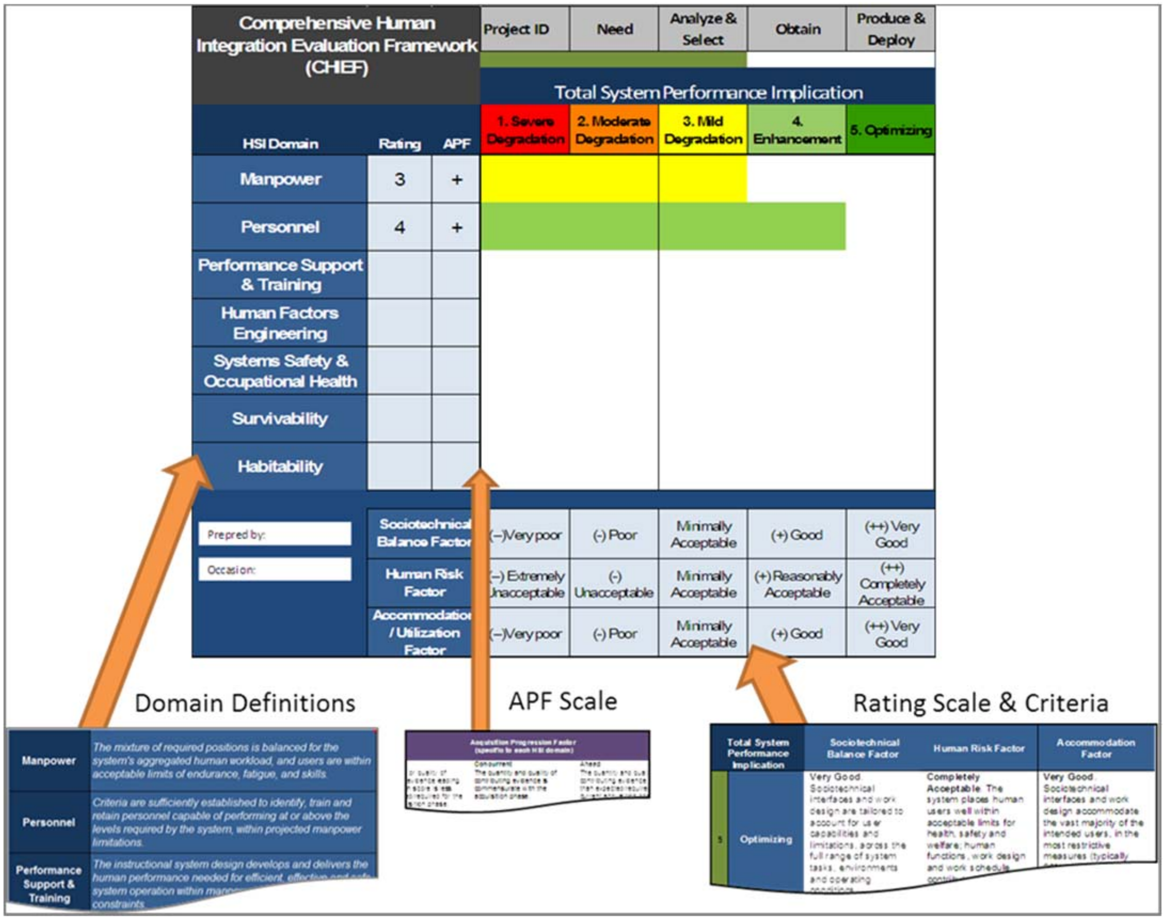


Figure 22. Final CHIEF components

The final version of the CHIEF rating system (at the top of Figure 22) includes other refinements from the final HSI Framework workshop. An indicator bar to display the current phase of acquisition (top) and information fields for the author and occasion for the rating (bottom left) were incorporated into the final design. Separate fields were included for the HSI domain rating and the acquisition performance factor.

The final version of the CHIEF rating system is configured as a "rolled-up" view, removing background information such as HSI domain descriptions and the aggregating measures seen in the initial HSI Framework. As determined in the final workshop, these fields remain hidden and can be is implemented as display-on-demand information when required. The rating scale criteria, aggregated measures, and APF scale are similarly hidden.

As will be discussed in the final chapter, incorporating on-demand display of information was considered highly desirable for future versions of CHIEF.

1. Suggested CHIEF Workflow

Figure 23 shows the notional workflow for developing CHIEF ratings, as conceptualized by the author and NPS HSI faculty, and validated by practitioners during the final HSI Framework refinement workshop.

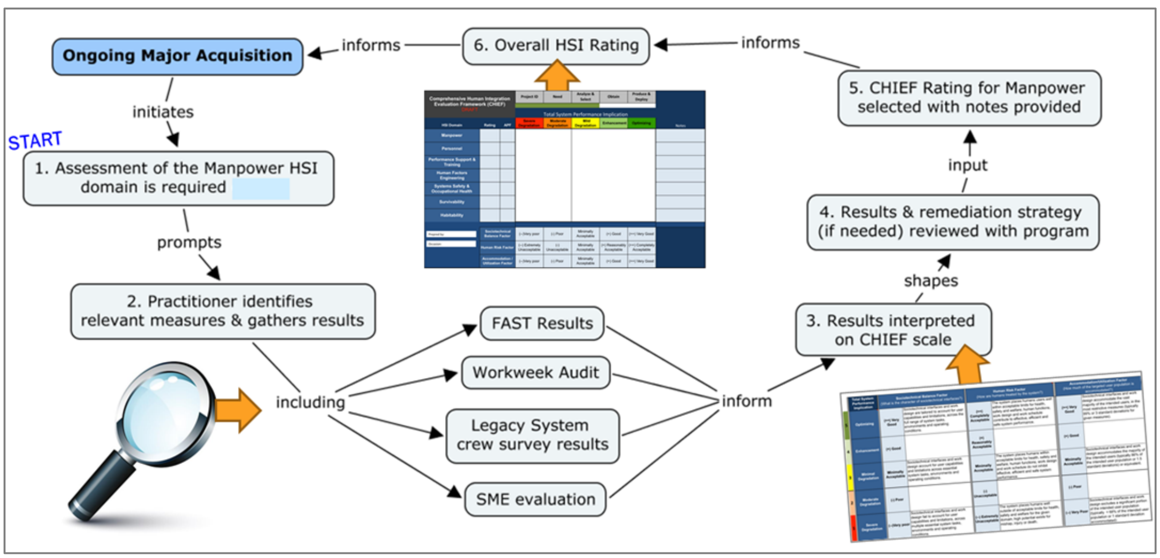


Figure 23. Example CHIEF workflow

The notional workflow for the development of CHIEF ratings can be summarized in six steps:

- Step One: The practitioner is assigned to evaluate HSI performance in the selected domain(s) for a given system. The

practitioner then reviews the consolidated domain definition to guide assessment.

- Step Two: The practitioner applies his or her experience to identify aggregating measures appropriate for the system; data from these measures are then collected for analysis.

- Step Three: The results from the data collected are consolidated and assessed using the CHIEF rating scales and criteria; the practitioner applies his or her knowledge to determine the impact of the selected domain(s) on total system performance (e.g., manpower in Figure 22).

- Step Four: Once the CHIEF domain rating has been assessed, the results and a remediation strategy (as required) are reviewed by a competent authority. Issues are resolved (if possible) at the appropriate organizational level.

- Step Five: The CHIEF domain rating is assigned, including a summary of aggregated measures, source documentation, and a resolution strategy for discrepancies (as required).

- Step Six: The individual CHIEF HSI domain ratings are consolidated with other domains for a comprehensive CHIEF assessment.

In addition to reducing the potential for error, a standardized CHIEF workflow offers other benefits. Administrative process controls can be implemented at any step, offering senior HSI practitioners and acquisitions managers insight into HSI activities as they evolve. A standard workflow also facilitates process automation through software, as discussed in the next chapter.

V. SUMMARY AND CONCLUSION

A. SUMMARY

This thesis documents the development of a simplified framework for understanding and assessing HSI across diverse disciplines of acquisition.

The proposed HSI Activity Model was developed to conceptualize HSI activity in military acquisition. Established human factors and human computer interaction theory was studied and applied to develop a concise view of HSI in action during military system acquisition. In this model, we summarized the core activity of HSI as the balancing of human capabilities and limitations with the affordances and constraints presented by system technology to accomplish system objectives.

Next, we developed the CHIEF rating system to provide a method for assessing HSI during acquisition. Existing system assessment measures, including TRL, were studied to determine criteria for a successful HSI measurement framework. A measurement approach, rating scales and criteria, and a consolidated scoring matrix were then developed for the framework in cooperation with HSI faculty from the Naval Postgraduate School. This initial version of CHIEF was refined during four workshops with Coast Guard HSI practitioners. As a culminating exercise, practitioners employed CHIEF to evaluate a major USCG acquisition program. The usability of the framework, notional workflow, and preferred scoring method were then refined.

Our research produced a usable framework, but revealed a number of necessary assumptions, limitations, and practical considerations that must be taken into account. These are discussed in the following sections.

B. EXAMINING CHIEF ASSUMPTIONS AND LIMITATIONS

The research, discussions, and scenarios carried out in CHIEF's development required a number of assumptions and revealed some potential limitations. The following emerged as common themes:

1. Subject Matter Expertise Is Essential

Effective use of CHIEF depends on the expertise of HSI practitioners. As seen in the proposed workflow (Figure 23), a CHIEF evaluation requires in-depth knowledge, skills, and abilities in the HSI domain. This becomes most evident during selection of aggregating measures and during interpretation of performance results using CHIEF rating scales. Developing an overall CHIEF rating across domains requires knowledge of, and experience with, overarching HSI policies and procedures. Without the required practitioner expertise, CHIEF ratings may very well be inaccurate.

2. Aggregating Measures Are Pivotal

The accuracy of CHIEF is predicated on relevant, valid, and reliable HSI TTAMs. Measures must be available to practitioners in areas that require measurement; program resources must also be available for aggregating measures to be planned for and collected in a timely fashion during acquisition. Establishing reliable measures is essential to the successful implementation of CHIEF as the standard for assessing the extent to which human and technological components form a healthy, synergistic bond that will achieve total system objectives.

3. Recognize Statistical and Representational Limitations

The system-wide HSI assessment proposed in CHIEF will require a wide variety of measures. Alignment of composite aggregating measures across CHIEF ratings scales will also require subjective interpretation, as noted earlier. For these reasons, data derived from CHIEF should be regarded as ordinal data (Stangor, 2010). The numerical scores generated by CHIEF imply the ability to

calculate an overall HSI average for an acquisition program, but this temptation should be resisted. Since no weighting scale is applied during the CHIEF rating process, a straightforward averaging of scores suggests equal weighting of all domains, regardless of system realities. Using an un-weighted mean when all domains are not equal will result in a skewed perception of HSI efficacy in the acquisition program.

CHIEF was conceived for conveying HSI understanding during key acquisition events. Thus, CHIEF results are expected to share limited space with other acquisition measures and information. Displaying individual CHIEF domain scores and supporting information may not be feasible. In circumstances where a composite HSI assessment is desired, using an average score based on the total system performance implication scale is suggested, supplemented with an indication of all domains rated below the acceptable level of performance (TSPI less than three). This will avoid underperforming domain scores from being obscured during averaging.

C. RECOMMENDED DIRECTIONS FOR FUTURE RESEARCH

The development of CHIEF was limited by the time and resources available for this thesis. Though functional, the elements of CHIEF require further refinement. Several promising areas for continued research are discussed below.

1. Continue Developing the CHIEF Software

Developing CHIEF to its full potential will require the framework to be placed into a usable format. The current spreadsheet-based version of CHIEF requires extensive user manipulation and has limited input and output. This was sufficient for research and rapid prototyping, but not for adoption as an accepted HSI business practice. Development of specific, dedicated software was beyond the scope of this effort. However, CHIEF’s development and refinement revealed many desirable attributes for future software application (see Appendix C). Overall, the workflow and design of DI’s SHARE software tool offers an excellent starting point for developing a CHIEF software architecture.

2. Refine CHIEF Rating Scale Criteria

One of the most challenging aspects of developing CHIEF was establishment of rating scale criteria. Criteria needed to be precise enough to discriminate between levels of HSI performance without extraneous detail. Criteria also needed to be compatible with aggregating measures across multiple HSI domains. The scales and criteria presented in this thesis were validated in the final workshop scenario, but with a relatively small group of practitioners in a controlled scenario. Additional subscales and criteria will likely be required to suit a broader range of practitioners, and more diverse evaluation scenarios.

3. Identify Suitable Aggregating Measures

As proposed in Chapter IV, aggregating measures evaluate as they interact with system components in relevant work context. The broad range of systems in modern military acquisition means that this context will vary widely. Enterprise software systems, major cutters, and unmanned aircraft, for instance, represent very different operational contexts and may require a different suite of HSI TTAM to capture desired measures. Using the CHIEF framework will require an organization to identify relevant measures for each specific type of system.

D. CONCLUSION

Carrying out effective HSI remains a critical challenge for the USCG, DHS, and DOD. This thesis breaks new ground to establish useful metrics towards this end. As the current body of research reveals, achieving the necessary integration of humans and technology is a complex and challenging task. The history of TRL suggests that decades may pass before human-centered system measures are embraced and fully incorporated into federal acquisitions. The best way to accelerate this timeline is to incorporate CHIEF into acquisition policy and require the use of CHIEF for each milestone decision. Similar to TRL ratings, if an acquisition program receives an unsatisfactory CHIEF rating, the program cannot proceed to the next phase until the integration of humans and technology is deemed acceptable.

We hope that this research and the products offered will expand awareness of how critical the human component is to modern systems acquisition. Our collective understanding of human–technology integration (or lack thereof) will determine the survival of our service members and shape our operational fortunes.

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APPENDIX A – HSI FIGURE OF MERIT

PART ONE

Domain	Manpower	Personnel	Performance Support & Training
Desired State	The correct number and mix of personnel required for system operation, maintenance and support is identified; manning reflects the full range of operations, work demands, operating conditions and deployment scheme for the system, given current and projected manpower estimates.	Human performance factors including, cognitive, physical, and sensory capabilities, knowledge, skills, abilities, and experience levels are identified and matched to system tasks and workload; criteria are developed to effectively recruit, select and train personnel for safe, efficient and effective system operation.	Competency requirements are established to reflect end-user tasks and workload; knowledge, skill and ability gaps are appropriately identified; training system is developed and match to end-user learning needs.
Design Concerns	*Manpower estimates, individual competencies, team competencies, occupational specialties, resilience, manpower estimates, task capacity, net workload, watch schedules, operating conditions, ship fill, deployment schedules, chronic fatigue levels*	*Target audience descriptors, knowledge, skills, aptitudes, experiences, traits, cognitive abilities, cognitive style, personality factors; workload, cognitive demands, task requirements, task duration, task frequency, task design, task environment, operating conditions*	*Knowledge, skills, aptitudes, experiences, cognitive abilities, cognitive style, personality factors; competencies, task demands, cognitive demands, subject matter, audience, learning styles, delivery mode, training infrastructure, instructional technology, instructional design, evaluation metrics*
Undesired State	The mix and/or number of personnel specified for the system exceeds allowable manpower for the system; manning is insufficient for the full range of operations, work demands, operating conditions and deployment scheme of the system.	Individual performance factors are poorly matched to system tasks, workload and skill requirements. Criteria are not adequately established or implemented for recruiting, selecting, training and retaining personnel that meet or exceed the required aptitudes and traits for the system.	Competency requirements are not matched with end-user tasks and workload; knowledge and skills gaps are inadequately understood or defined; training system is incompatible with end-users learning needs and environment; delivery and retention of job-relevant knowledge, skills and abilities is inadequate.
References	DAG Chapter 6.3 AF HSI Handbook MANPRINT Handbook CG MSAM	DAG Chapter 6.3 AF HSI Handbook MANPRINT Handbook CG MSAM	DAG Chapter 6.3 AF HSI Handbook MANPRINT Handbook CG MSAM

PART TWO

Domain	Human Factors Engineering			
	Anthropometry	Ergonomics	Cognitive Engineering	Macro Ergonomics
Desired State	Physical characteristics, capabilities and limitations of the expected user population are established; physical interfaces including seating, racks, workstations, worksites, accesses and touch points accommodate the full user population.	Functional interfaces including controls, displays, workstations, worksites, accesses, labeling and touch points are configured for effective, efficient and safe operation given the expected user population.	Cognitive interfaces, processes and information flows are optimized for end-user cognitive abilities; end-user cognitive resources including memory, attention and decision making anchor the system design.	Cooperative interfaces are optimized to enable and enhance team performance, collaboration and communication; organizational interfaces are reflective of the projected operating conditions and deployment scheme of the system.
Design Concerns	*User physical characteristics, proportions and dimensions, anthropometric surveys, physical strength, range of motion, range of perception; accessibility, adjustability, configurability, modularity*	*Reaction time, attention, working memory; display placement, information management, equipment arrangement, color coding, gestalt principles, labeling, grouping of controls, ease of use, usability, task load index*	*Attention cues, cognitive workload, decision rules, decision support systems, situation awareness, mental models, cognitive skills and attitudes, warnings and alarms, function allocation (humans vs. automation)*	*Job design, operating policies and procedures, watch floor and workstation arrangement; communication scheme, watch team, management interfaces, crew/team coordination, shared mental models.*
Undesired State	Capabilities and limitations of the expected user population are not fully understood & applied; tasks and work areas are inadequately arranged, or are not configurable to accommodate the full user population.	Physical and virtual interfaces are not configured for effective, efficient and safe operation; interfaces, controls or other touch points do not recognize and incorporate physical capabilities and limitations of expected users.	Cognitive workload, processes and information flows are incompatible with, or exceed end-user cognitive capabilities; functional allocation (automation) poorly balances human cognitive abilities and system capabilities.	Cooperative interfaces are optimized for team performance, collaboration, and inter-user communication; organizational interfaces reflect system operating conditions, constraints and limitations.
References	MILSTD 1472-G AF HSI Handbook MANPRINT Handbook Pheasant & Haslegrave (2006) CG MSAM	DAG Chapter 6.3.4 MILSTD 1472-G AF HSI Handbook MANPRINT Handbook CG MSAM	DAG Chapter 6.3.4 MILSTD 1472-G AF HSI Handbook MANPRINT Handbook CG MSAM	DAG Chapter 6.3.4 MILSTD 1472-G AF HSI Handbook MANPRINT Handbook CG MSAM

PART THREE

Domain	Systems Safety & Occupational Health	Habitability	Survivability
Desired State	The full extent of potential acute and chronic hazards to personnel are fully understood; hazards are reduced, eliminated or mitigated commensurate with expected operations to minimize risk of acute and chronic injuries to the expected user population.	Living and working conditions are conducive to sustaining the morale, safety, health, and comfort of the user population; living and working conditions enhance personnel effectiveness and mission accomplishment, and encourage recruitment and retention.	System is configured to reduce the risk of fratricide, detection, and the probability of being attacked commensurate with projected operations; users are able to withstand hostile environments without aborting the mission or acute chronic illness, disability, or death.
Design Concerns	*Walking/working surfaces, work at heights, pressure extremes, lock-out/tag-out, fire hazards, and explosive risk; shock hazards, noise, light, vibration, chemical exposure, radiological exposure, repetitive motion; psychological risk factors*	*Lighting, space, ventilation, and sanitation; noise and temperature control; ship motion; religious, medical, and food services quality and availability; berthing, bathing, and personal hygiene, non-operational connectivity*	*Crew compartment integrity, egress capability, emergency/rescue access; armor, ballistic protection, fire protection, fire suppression, decontamination capability; fratricide, detectability, resilience, reparability*
Undesired State	The system fails to reduce, eliminate or mitigate personnel hazards to an acceptable level for expected operations; system is not adequately configured to minimize risk of acute and chronic injuries to the expected user population.	Living or working conditions inhibit the morale, safety, health and/or comfort of system end-users. Living or working conditions diminish personnel effectiveness and mission accomplishment, and/or diminish recruitment and retention.	System fails to adequately reduce the risk of fratricide, detection, and the probability of being attacked in projected operations; users are unable to withstand hostile environments without aborting the mission and/or suffering acute chronic illness or injury.
References	DAG Chapter 6.3.4 MILSTD 1472-G AF HSI Handbook MANPRINT Handbook CG MSAM	DAG Chapter 6.3.4 MILSTD 1472-G MANPRINT Handbook CG MSAM	DAG Chapter 6.3.4 MILSTD 1472-G AF HSI Handbook MANPRINT Handbook CG MSAM

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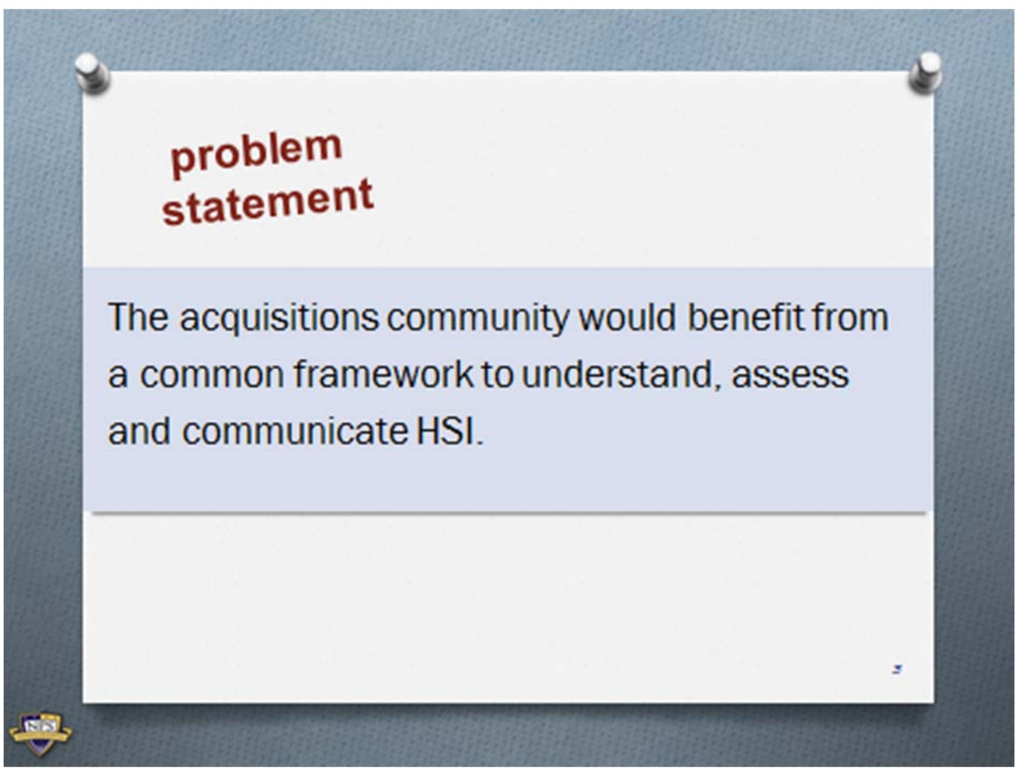
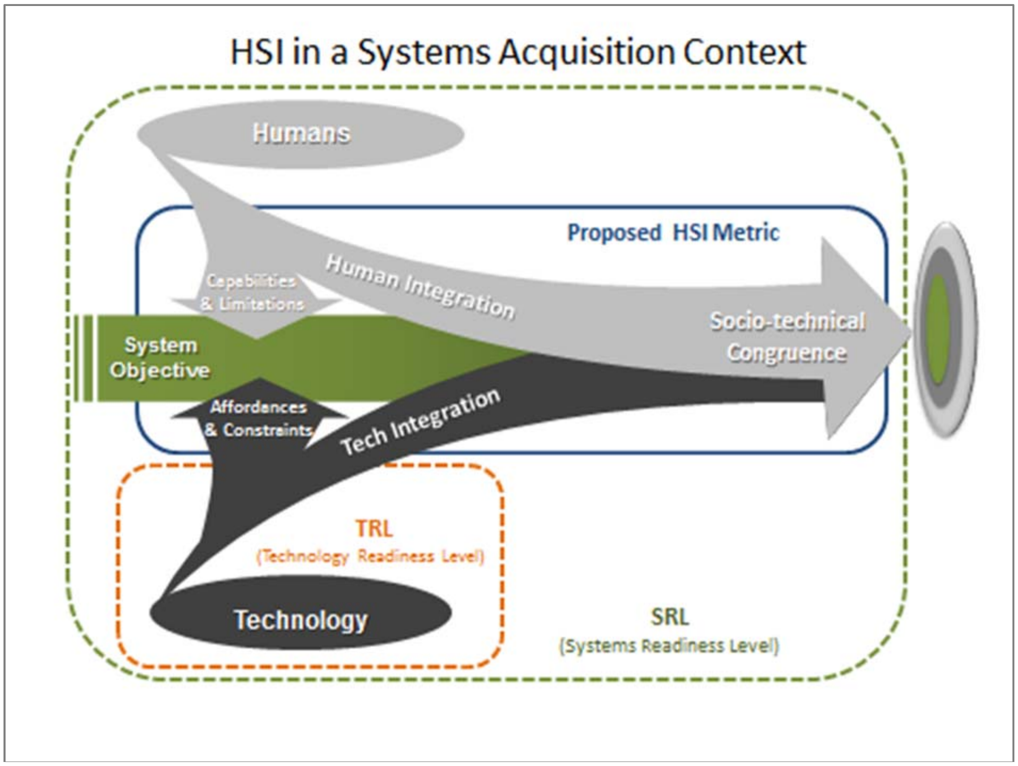
APPENDIX B – WORKSHOP MATERIALS

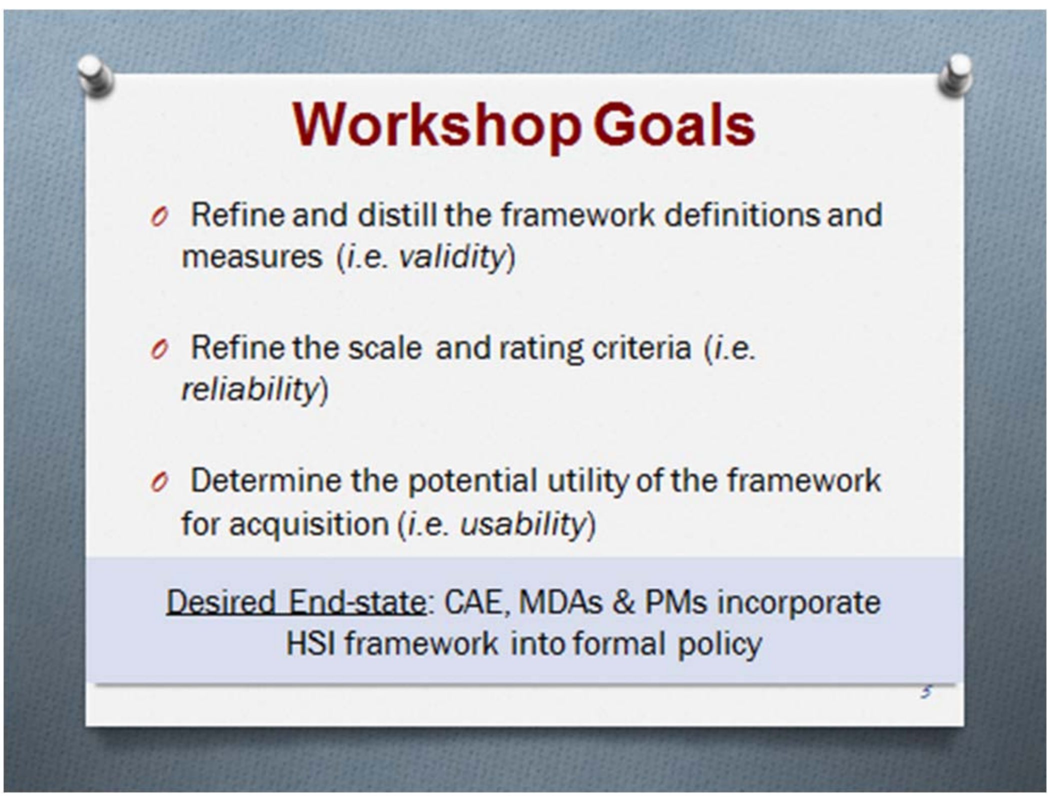
NPS COLLABORATION SITE SCREENSHOT

WORKSHOP ONE PRESENTATION

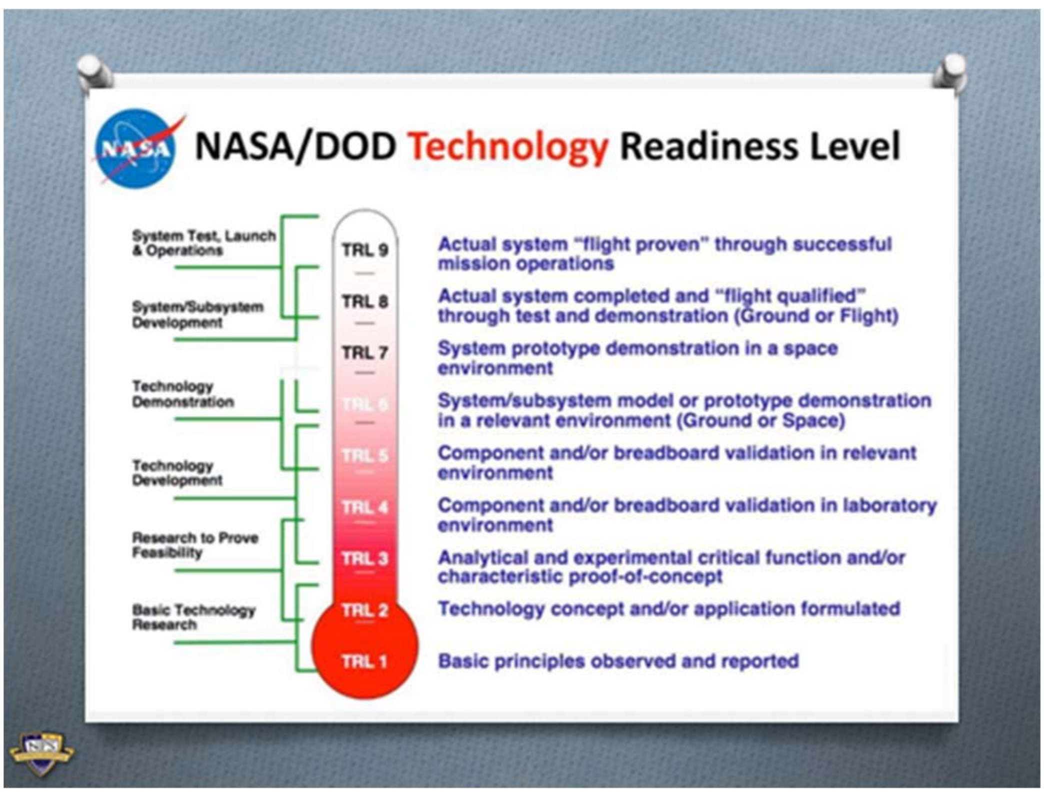

Housekeeping
Roles
Participation / Non-attribution
Elluminate Sessions Recorded
Access to Final Product
My Contact Info:


problem statement
The acquisitions community would benefit from a common framework to understand, assess and communicate HSI.


HSI in a Systems Acquisition Context
Humans
Proposed HSI Metric
Human Integration
Capabilities & Limitations
System Objective
Socio-technical Congruence
Affordances & Constraints
Tech Integration
TRL
(Technology Readiness Level)
Technology
SRL
(Systems Readiness Level)


Workshop Goals
Refine and distill the framework definitions and measures (i.e. validity)
Refine the scale and rating criteria (i.e. reliability)
Determine the potential utility of the framework for acquisition (i.e. usability)
Desired End-state: CAE, MDAs & PMs incorporate HSI framework into formal policy


Lessons from Technology Readiness Levels (TRL)


NASA/DOD Technology Readiness Level
System Test, Launch & Operations
System/Subsystem Development
Technology Demonstration
Technology Development
Research to Prove Feasibility
Basic Technology Research
TRL 9
TRL 8
TRL 7
TRL 6
TRL 5
TRL 4
TRL 3
TRL 2
TRL 1
Actual system "flight proven" through successful mission operations
Actual system completed and "flight qualified" through test and demonstration (Ground or Flight)
System prototype demonstration in a space environment
System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
Component and/or breadboard validation in relevant environment
Component and/or breadboard validation in laboratory environment
Analytical and experimental critical function and/or characteristic proof-of-concept
Technology concept and/or application formulated
Basic principles observed and reported

Why have TRLs become the coin of the realm?

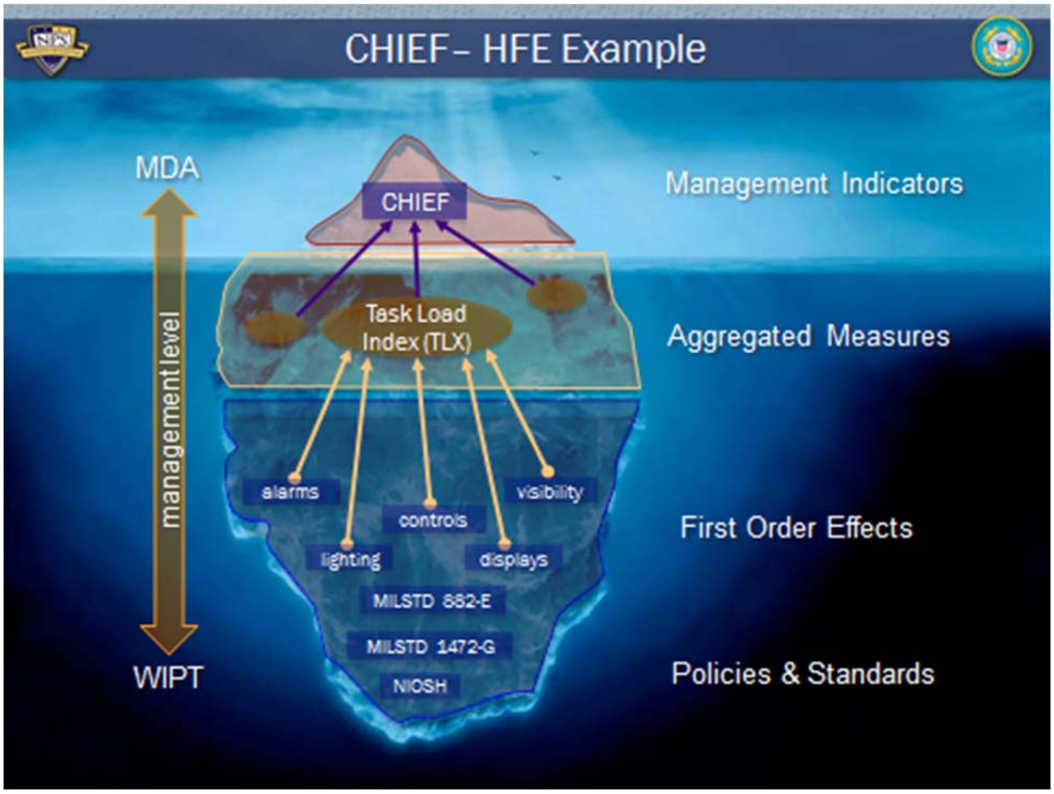
- *Aggregated*
- *Simplified*
- *Discipline-independent*
- *'Figure of Merit' based*

(Source: Mankins 2009)

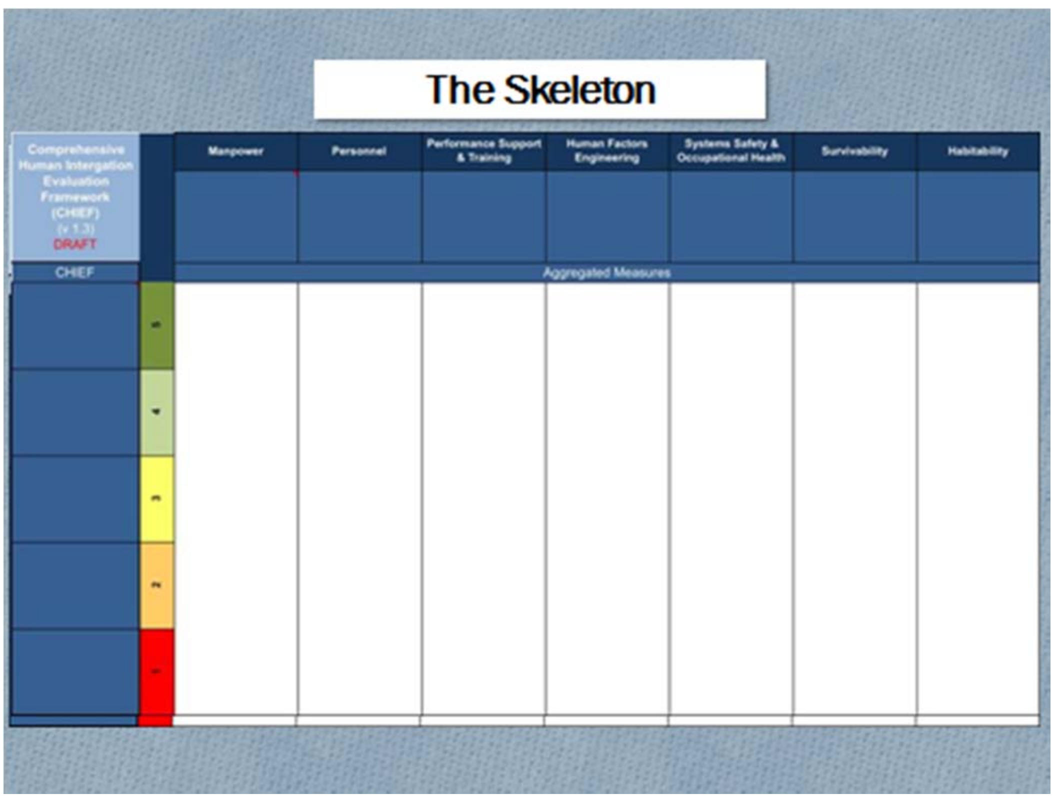
Building a Comprehensive Human Integration Evaluation Framework

(CHIEF)

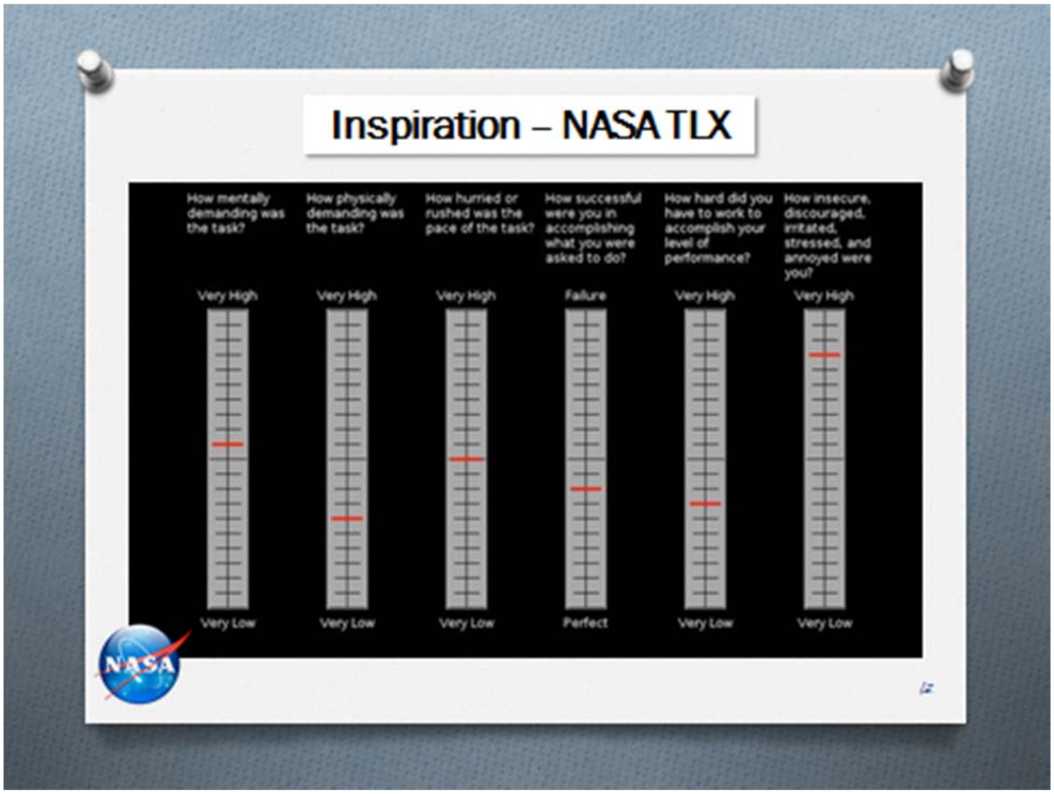
(When you want a no kidding assessment, you ask the Chief…)

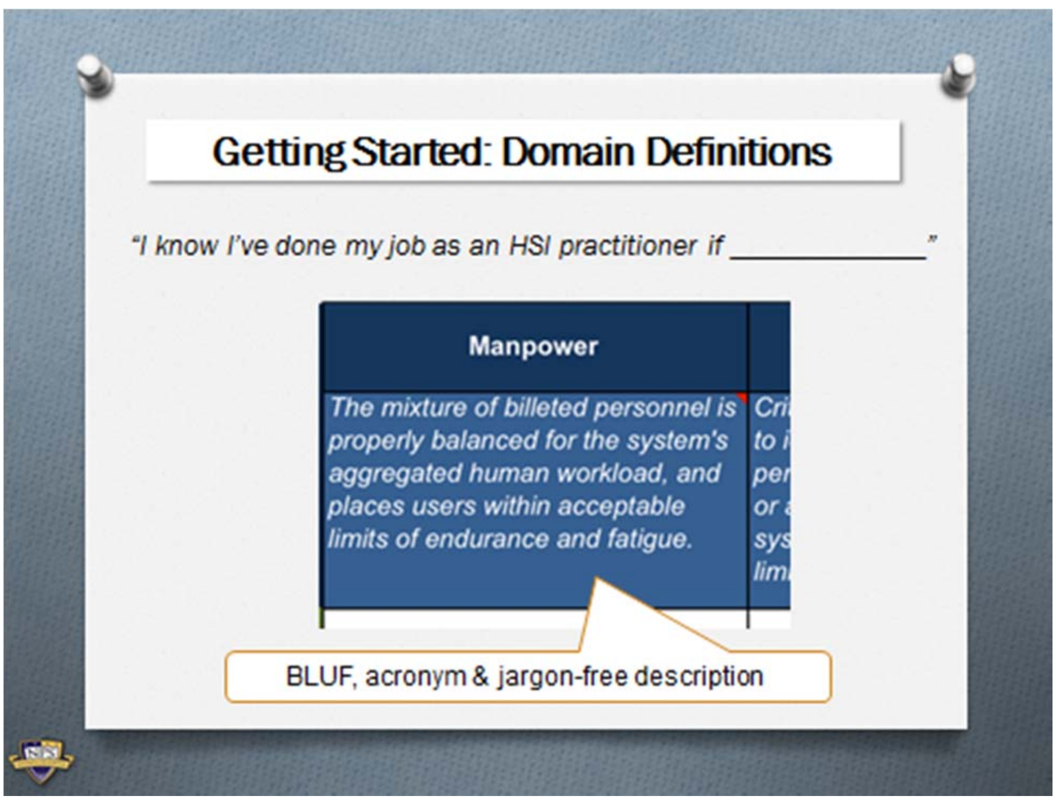


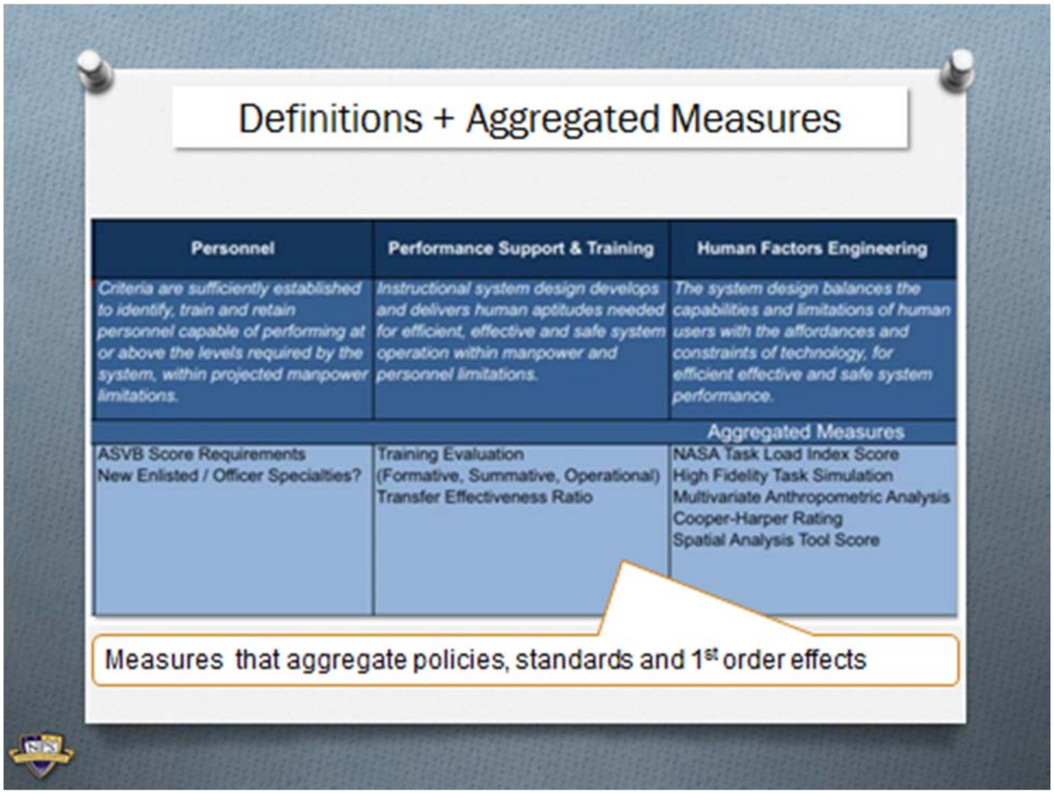
CHIEF– HFE Example
MDA
management level
WIPT
CHIEF
Task Load Index (TLX)
alarms
controls
visibility
lighting
displays
MILSTD 882-E
MILSTD 1472-G
NIOSH
Management Indicators
Aggregated Measures
First Order Effects
Policies & Standards



The Skeleton
Comprehensive Human Intergation Evaluation Framework (CHIEF) (v 1.3)
DRAFT
Manpower
Personnel
Performance Support & Training
Human Factors Engineering
Systems Safety & Occupational Health
Survivability
Habitability
CHIEF
Aggregated Measures

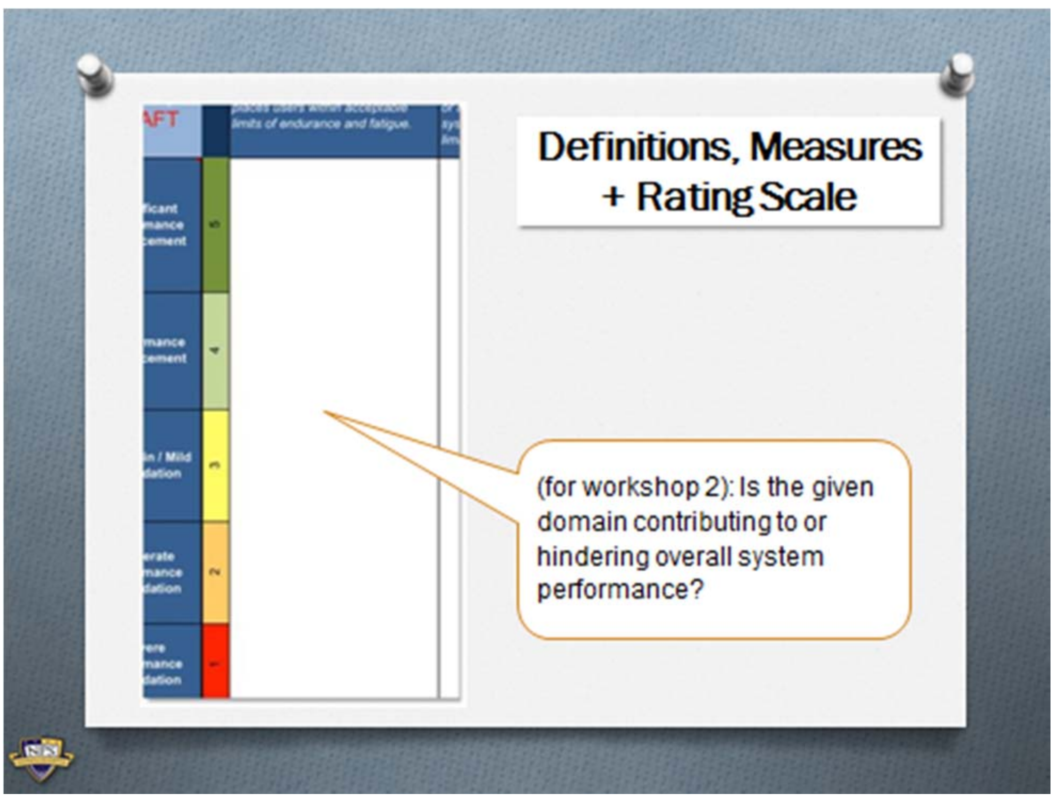

Inspiration – NASA TLX
How mentally demanding was the task?
How physically demanding was the task?
How hurried or rushed was the pace of the task?
How successful were you in accomplishing what you were asked to do?
How hard did you have to work to accomplish your level of performance?
How insecure, discouraged, irritated, stressed, and annoyed were you?
Very High
Very High
Very High
Failure
Very High
Very High
Very Low
Very Low
Very Low
Perfect
Very Low
Very Low
NASA

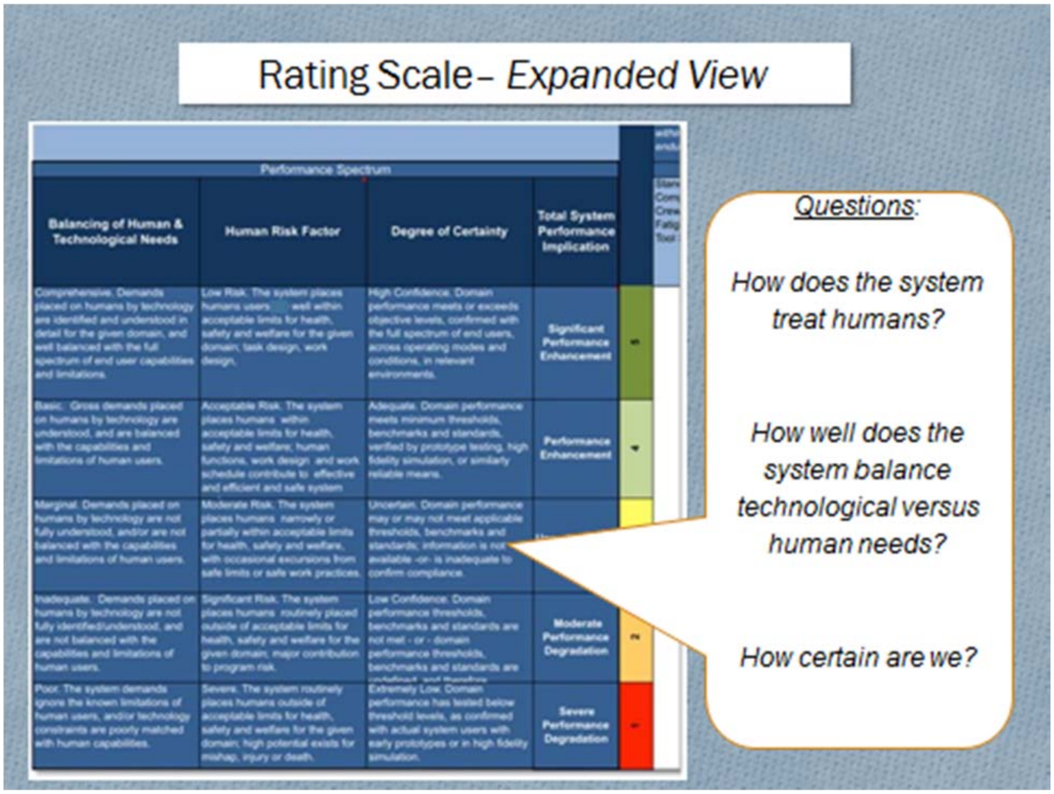

Getting Started: Domain Definitions
"I know I've done my job as an HSI practitioner if ____________"
Manpower
The mixture of billeted personnel is properly balanced for the system's aggregated human workload, and places users within acceptable limits of endurance and fatigue.
BLUF, acronym & jargon-free description

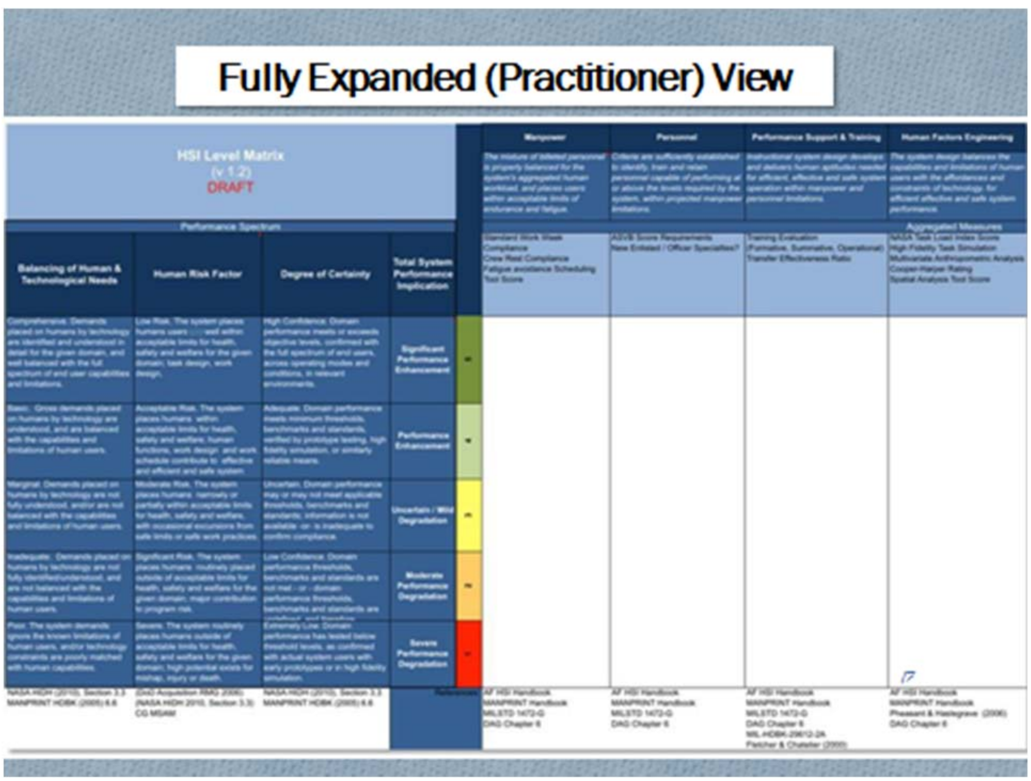

Definitions + Aggregated Measures

Personnel	Performance Support & Training	Human Factors Engineering
Criteria are sufficiently established to identify, train and retain personnel capable of performing at or above the levels required by the system, within projected manpower limitations.	*Instructional system design develops and delivers human aptitudes needed for efficient, effective and safe system operation within manpower and personnel limitations.*	*The system design balances the capabilities and limitations of human users with the affordances and constraints of technology, for efficient effective and safe system performance.*
		Aggregated Measures
ASVB Score Requirements New Enlisted / Officer Specialties?	Training Evaluation (Formative, Summative, Operational) Transfer Effectiveness Ratio	NASA Task Load Index Score High Fidelity Task Simulation Multivariate Anthropometric Analysis Cooper-Harper Rating Spatial Analysis Tool Score

Measures that aggregate policies, standards and 1st order effects

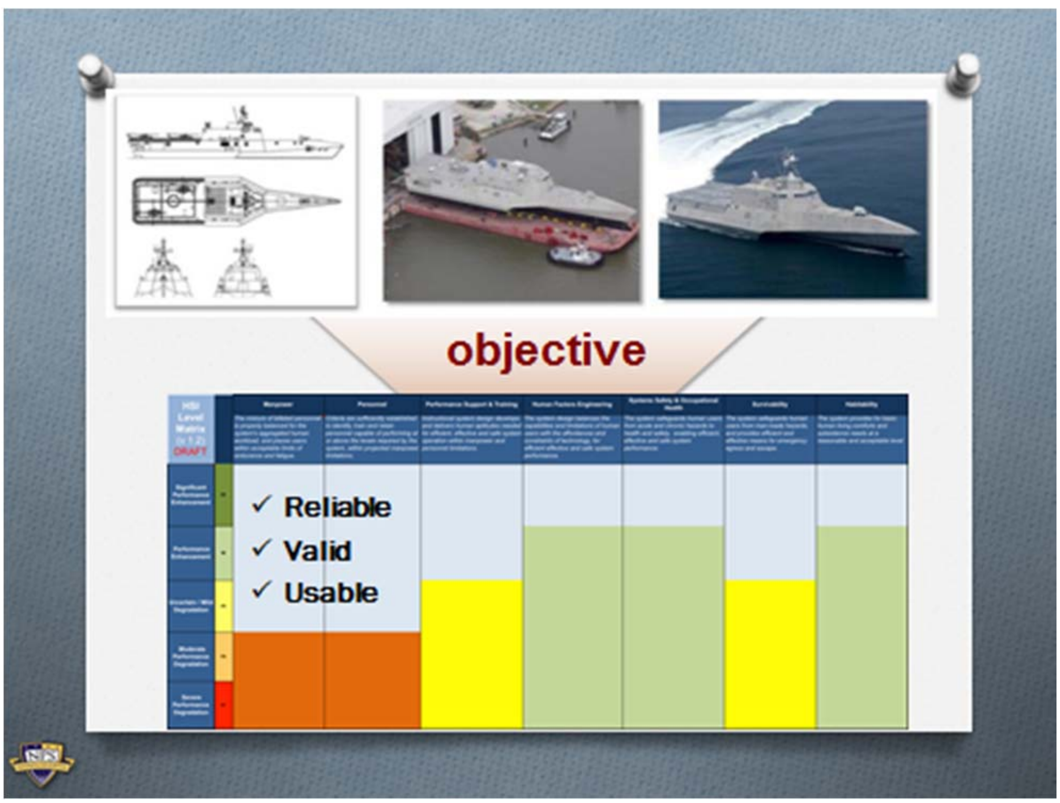

limits of endurance and fatigue.
5
4
3
2
1
Definitions, Measures + Rating Scale
(for workshop 2): Is the given domain contributing to or hindering overall system performance?

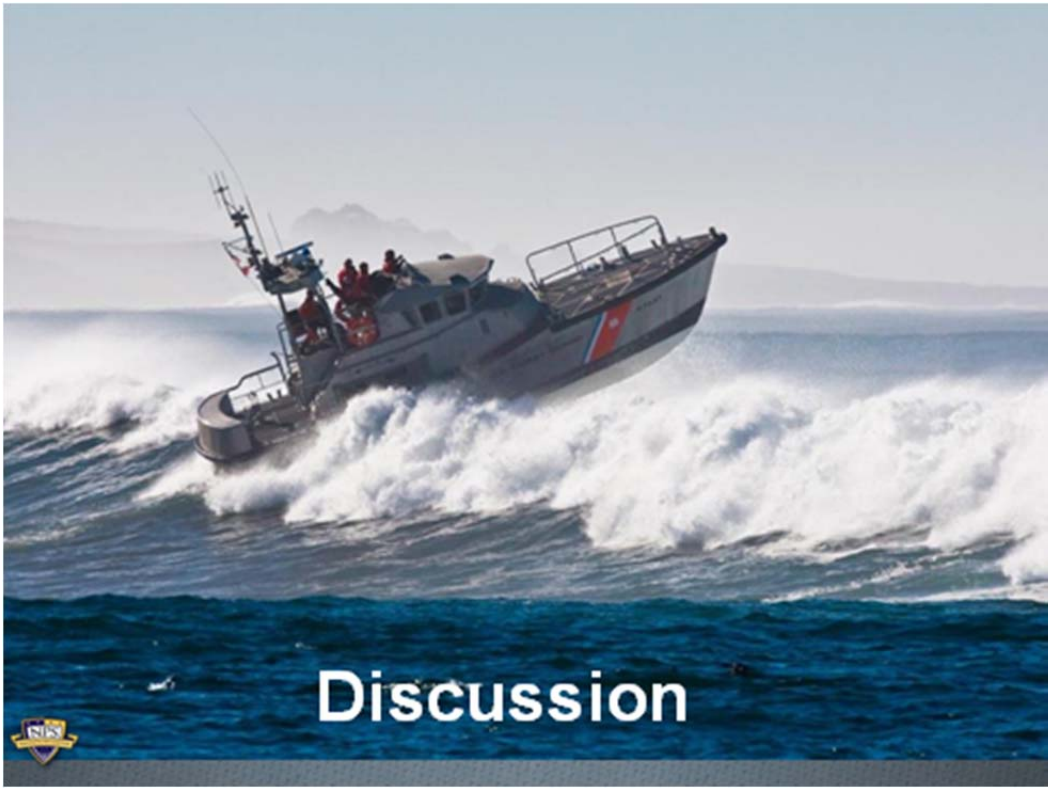

Rating Scale – *Expanded View*
Performance Spectrum
Balancing of Human & Technological Needs
Human Risk Factor
Degree of Certainty
Total System Performance Implication
Significant Performance Enhancement
Performance Enhancement
Moderate Performance Degradation
Severe Performance Degradation
Questions:
How does the system treat humans?
How well does the system balance technological versus human needs?
How certain are we?

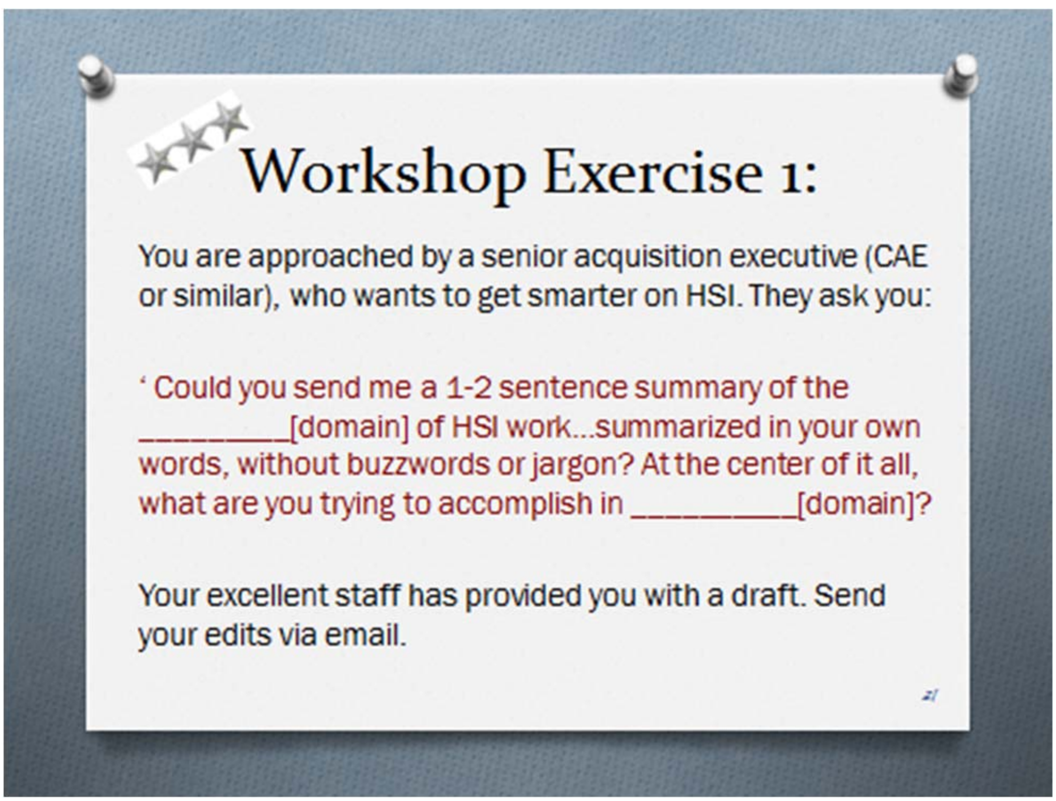

Fully Expanded (Practitioner) View
HSI Level Matrix
(v 1.2)
DRAFT
Performance Spectrum
Balancing of Human & Technological Needs
Human Risk Factor
Degree of Certainty
Total System Performance Implication
Manpower
Personnel
Performance Support & Training
Human Factors Engineering
Aggregated Measures

C.H.I.E.F. Assumptions

- Based on current state of the system at any point in acquisition process
- Assumes technology will function as advertised
- Expertise is required to correctly apply the tool

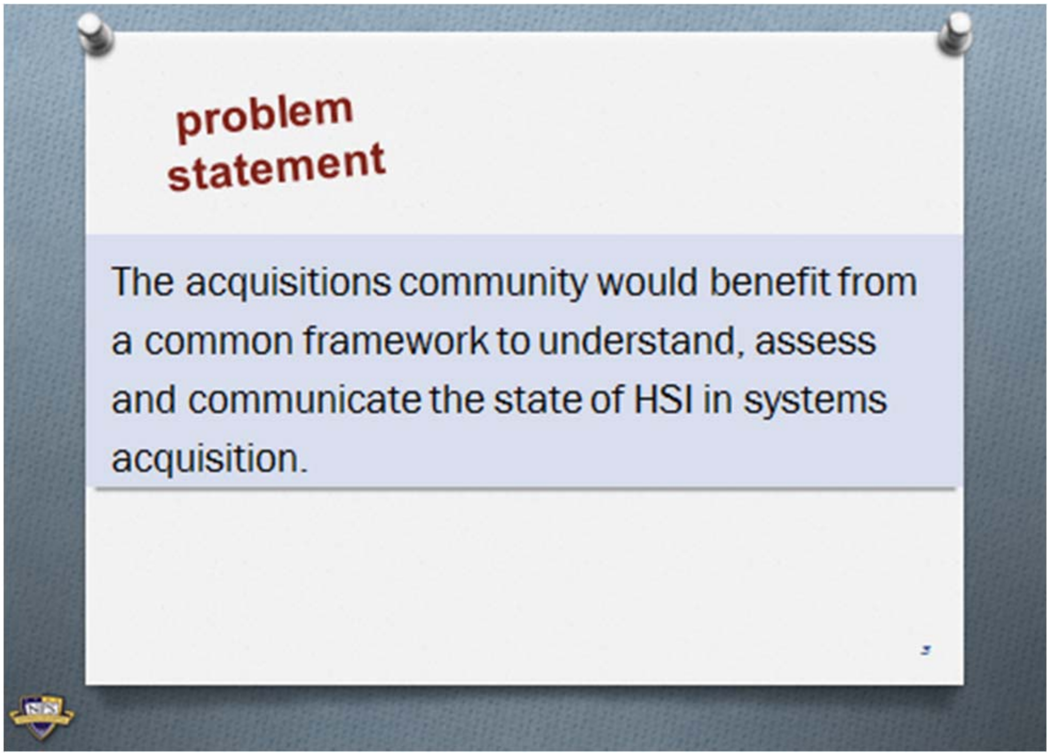


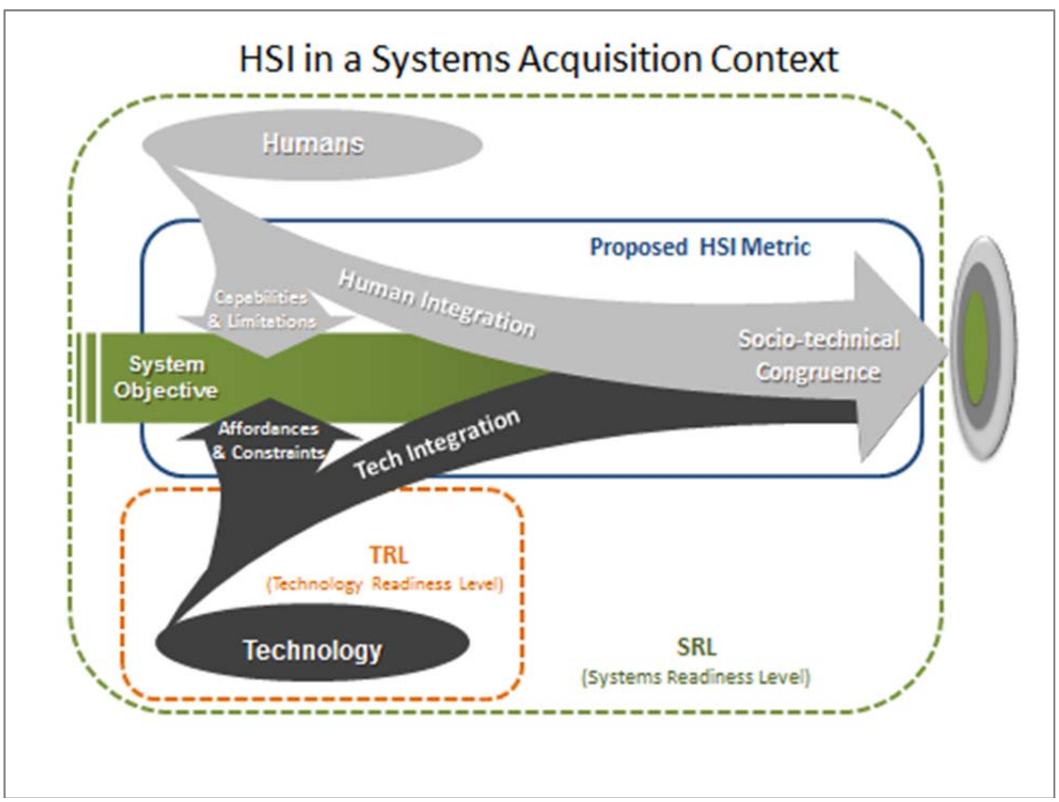

Discussion

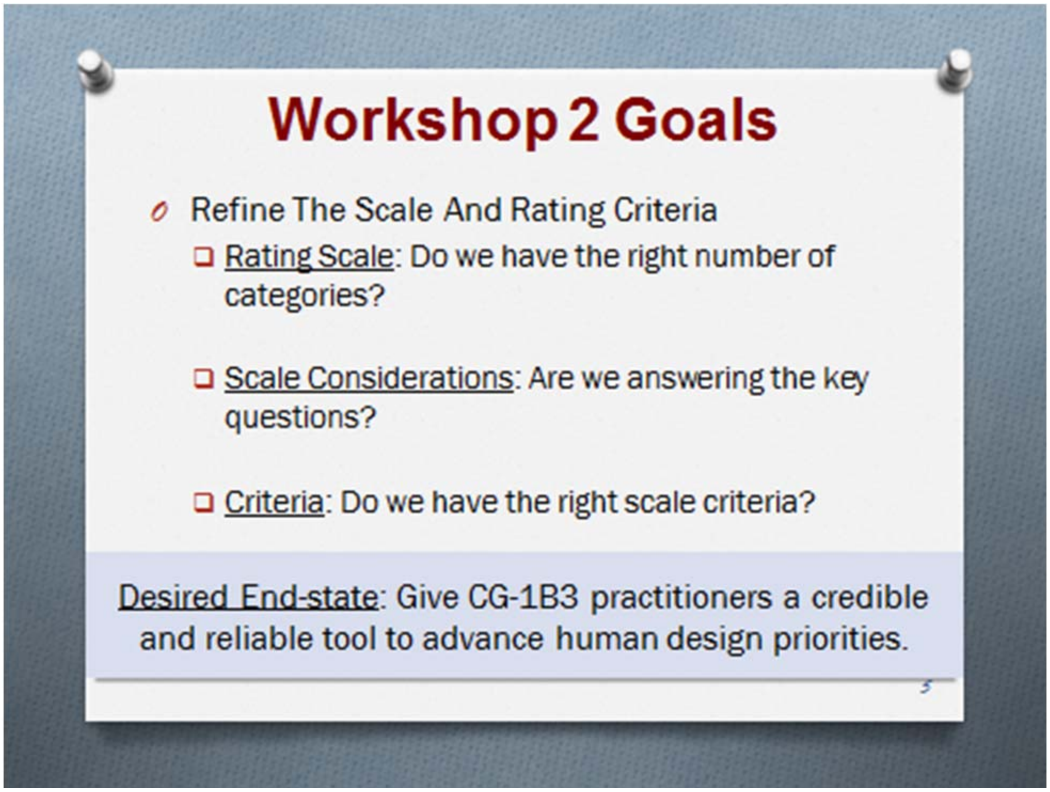

Workshop Exercise 1:
You are approached by a senior acquisition executive (CAE or similar), who wants to get smarter on HSI. They ask you:
' Could you send me a 1-2 sentence summary of the _________[domain] of HSI work...summarized in your own words, without buzzwords or jargon? At the center of it all, what are you trying to accomplish in __________[domain]?
Your excellent staff has provided you with a draft. Send your edits via email.


Day One Wrap Up
25

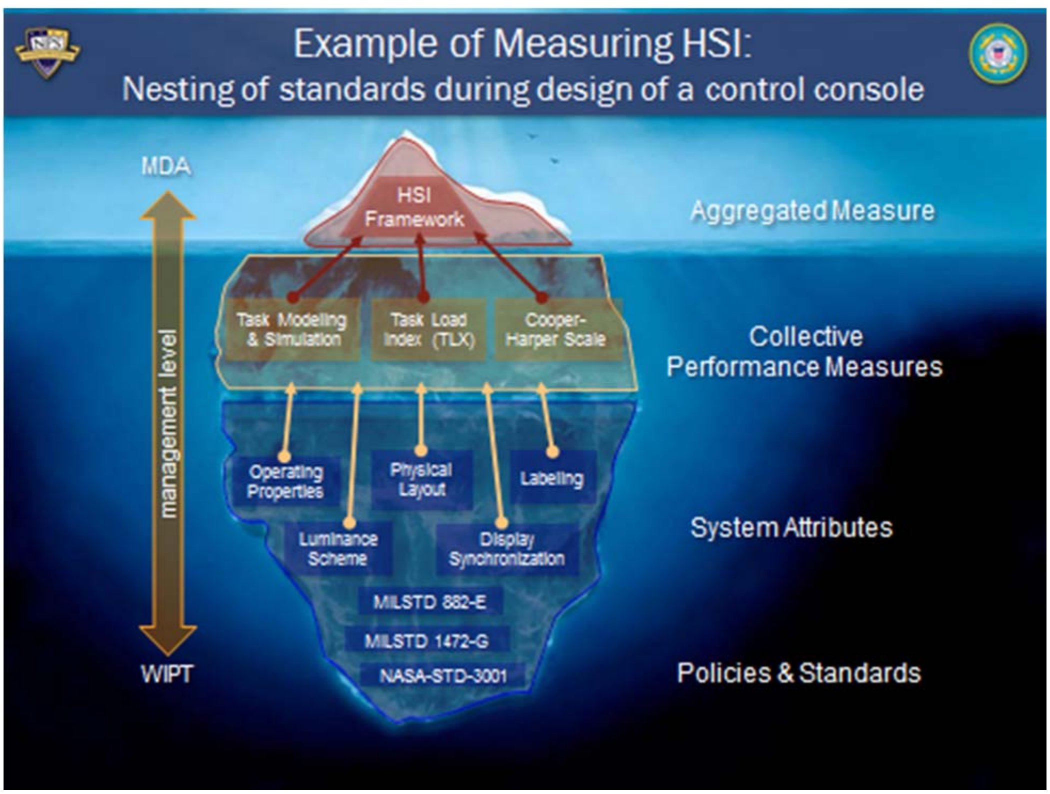
WORKSHOP TWO PRESENTATION


problem
statement
The acquisitions community would benefit from a common framework to understand, assess and communicate the state of HSI in systems acquisition.

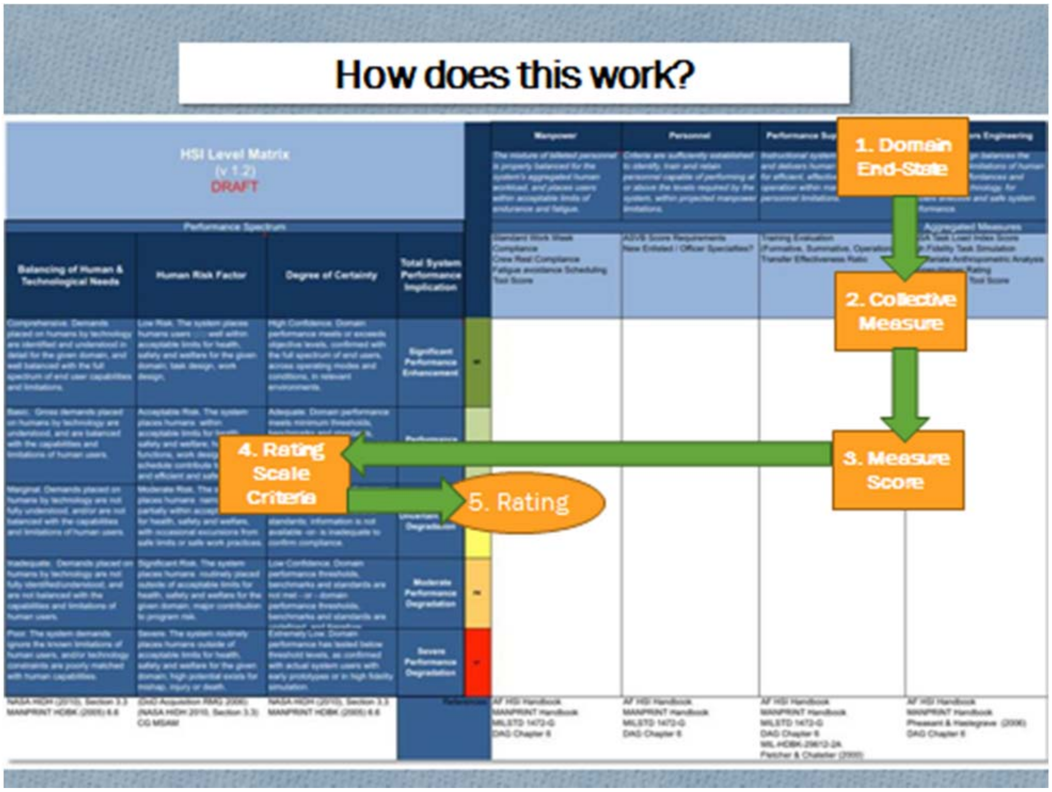

HSI in a Systems Acquisition Context
Humans
Proposed HSI Metric
Capabilities
& Limitations
Human Integration
Socio-technical
Congruence
System
Objective
Affordances
& Constraints
Tech Integration
TRL
(Technology Readiness Level)
Technology
SRL
(Systems Readiness Level)

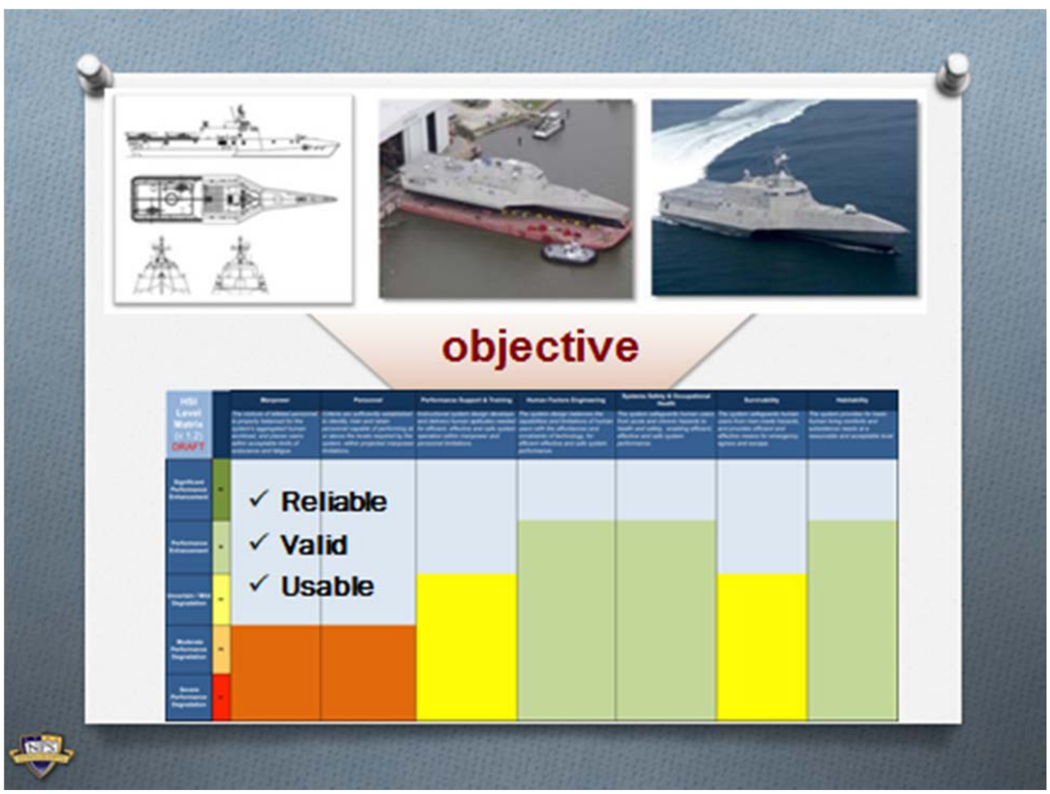


Workshop 2 Goals
Refine The Scale And Rating Criteria
Rating Scale: Do we have the right number of categories?
Scale Considerations: Are we answering the key questions?
Criteria: Do we have the right scale criteria?
Desired End-state: Give CG-1B3 practitioners a credible and reliable tool to advance human design priorities.

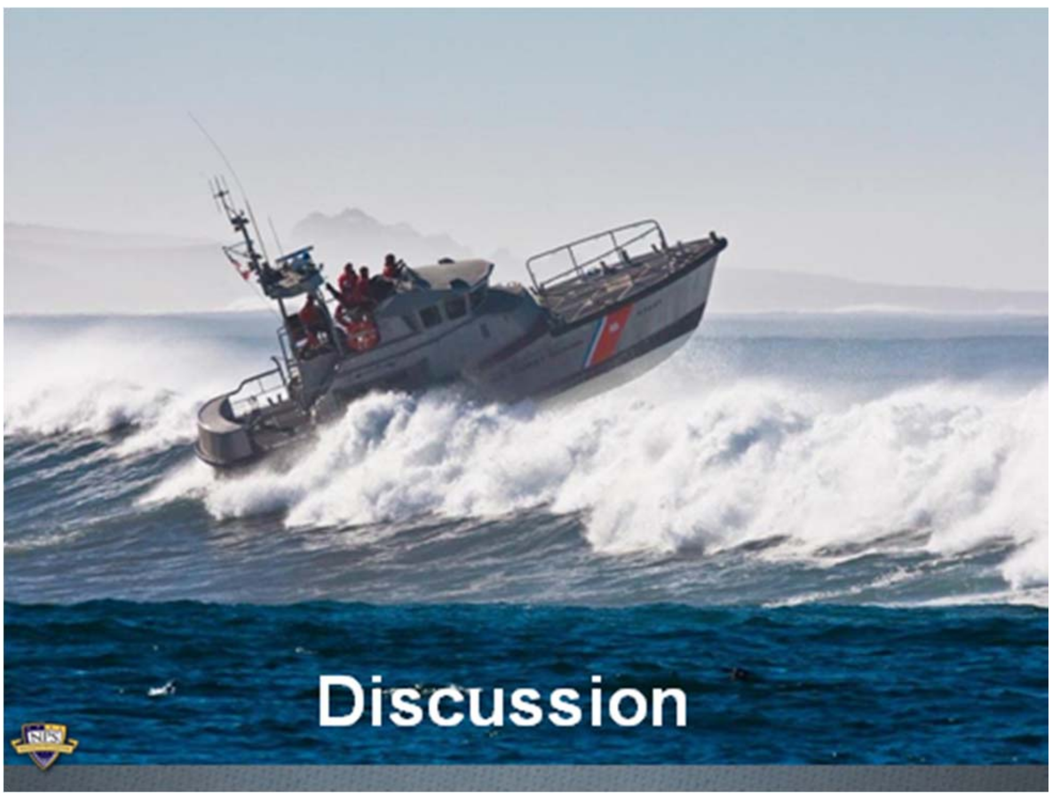


Example of Measuring HSI:
Nesting of standards during design of a control console
MDA
management level
WIPT
HSI Framework
Aggregated Measure
Task Modeling & Simulation
Task Load Index (TLX)
Cooper-Harper Scale
Collective Performance Measures
Operating Properties
Physical Layout
Labeling
Luminance Scheme
Display Synchronization
System Attributes
MILSTD 882-E
MILSTD 1472-G
NASA-STD-3001
Policies & Standards


How does this work?
HSI Level Matrix
(v 1.2)
DRAFT
1. Domain End-State
2. Collective Measure
3. Measure Score
4. Rating Scale Criteria
5. Rating


objective
✓ Reliable
✓ Valid
✓ Usable

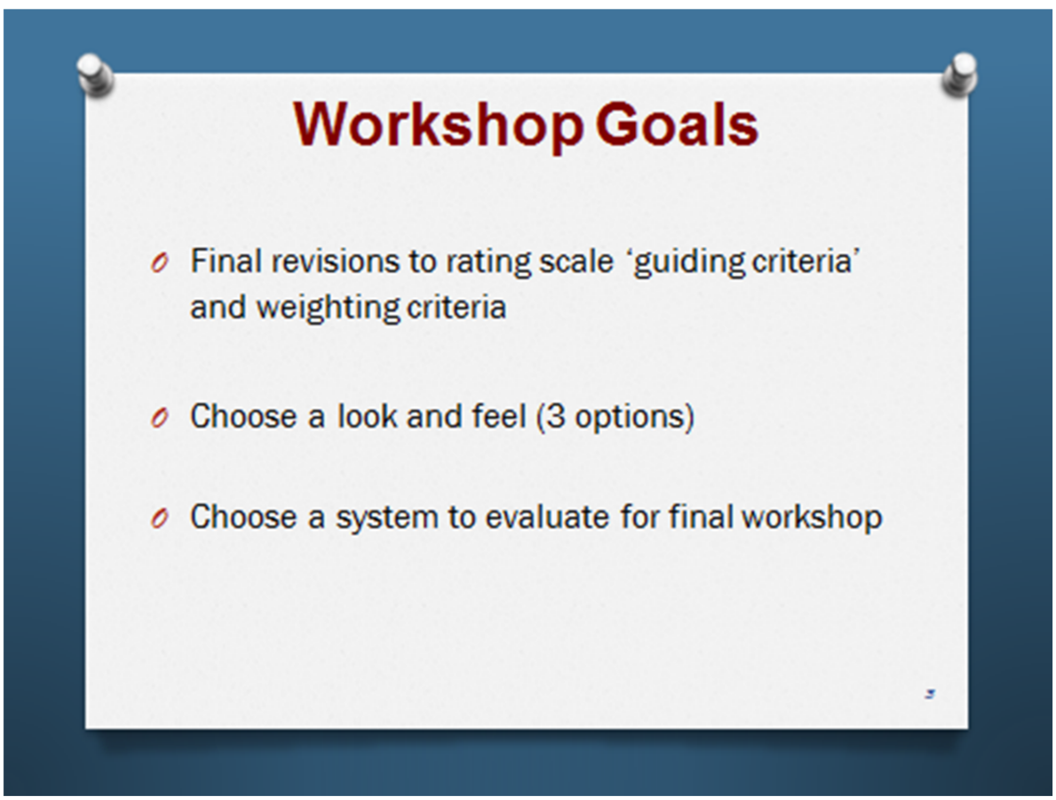
Balancing of Human & Technological Needs	States	Human Risk Factor	States	Weight of Contributing Evidence	States
Very Good	The limitations of human users are fully understood and accounted for across the system for the given domain; application of technology is tailored for optimal leveraging of human capabilities to fulfill technology constraints.	Completely Acceptable	The system places humans' tasks are well within acceptable limits for health, safety and welfare for the given domain; task design, work design.	(++) Validated as Positive	Domain performance meets or exceeds minimum thresholds, benchmarks and standards confirmed across the spectrum of end users, operating modes and conditions, in relevant environments.
Good	The limitations of human users are understood and accounted for in system design for the given domain; application of technology is tailored for effective use of human capabilities to fulfill technology constraints.	Reasonably Acceptable	The system places humans within acceptable limits for health, safety and welfare; human functions, work design and work schedule contribute to effective and efficient and safe system performance.	(+) Verified as Positive	Domain performance meets or is predicted to meet minimum thresholds, benchmarks and standards, verified by prototype testing, high fidelity simulation, or similarly reliable means.
Borderline	The limitations of human users are not fully accounted for in the system design; the application of technology fails to leverage available human capabilities - or borders on exceeding human capabilities.	Borderline	The system places humans narrowly or partially within acceptable limits for health, safety and welfare, with occasional excursions from safe limits or safe work practices.	(0) Inconclusive or Unavailable	Domain performance may or may not meet applicable thresholds, benchmarks and standards; information derived from testing or simulation is not available or is inadequate to confirm compliance.
Poor	Human capabilities and limitations are poorly matched to system aggregated tasks and workload; technology unnecessarily impedes, impairs or poorly human capabilities with technology	Unacceptable	The system places humans routinely placed outside of acceptable limits for health, safety and welfare for the given domain; major contribution to program risk.	(-) Verified as Negative	Domain performance thresholds, benchmarks and standards are not met - or - domain performance thresholds, benchmarks and standards are undefined, and therefore unassessed.
Very poor	Human capabilities and limitations are very poorly accounted for in the system design; the application of technology unnecessarily and unacceptably impairs human capabilities to fulfill technology constraints.	Extremely Unacceptable	The system routinely places humans outside of acceptable limits for health, safety and welfare for the given domain; high potential exists for mishap, injury or death.	(--) Validated as Negative	Extremely Low: Domain performance has tested below threshold levels, as confirmed with actual system users in prototypes or in high fidelity simulation.

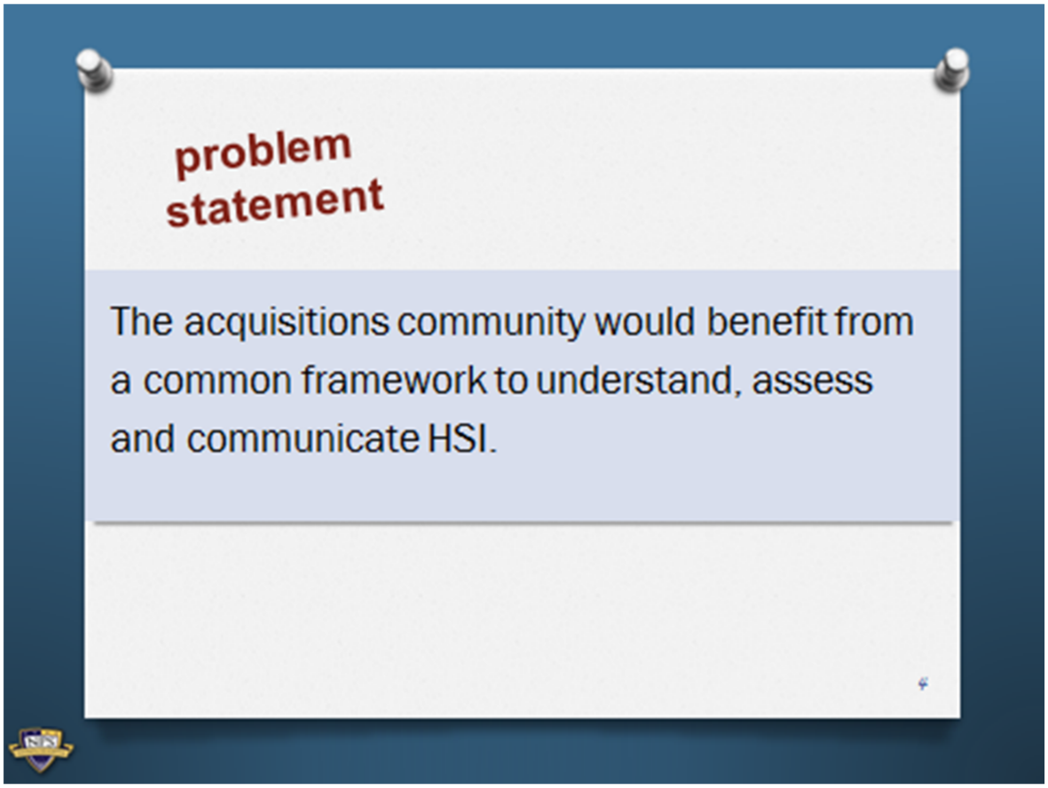


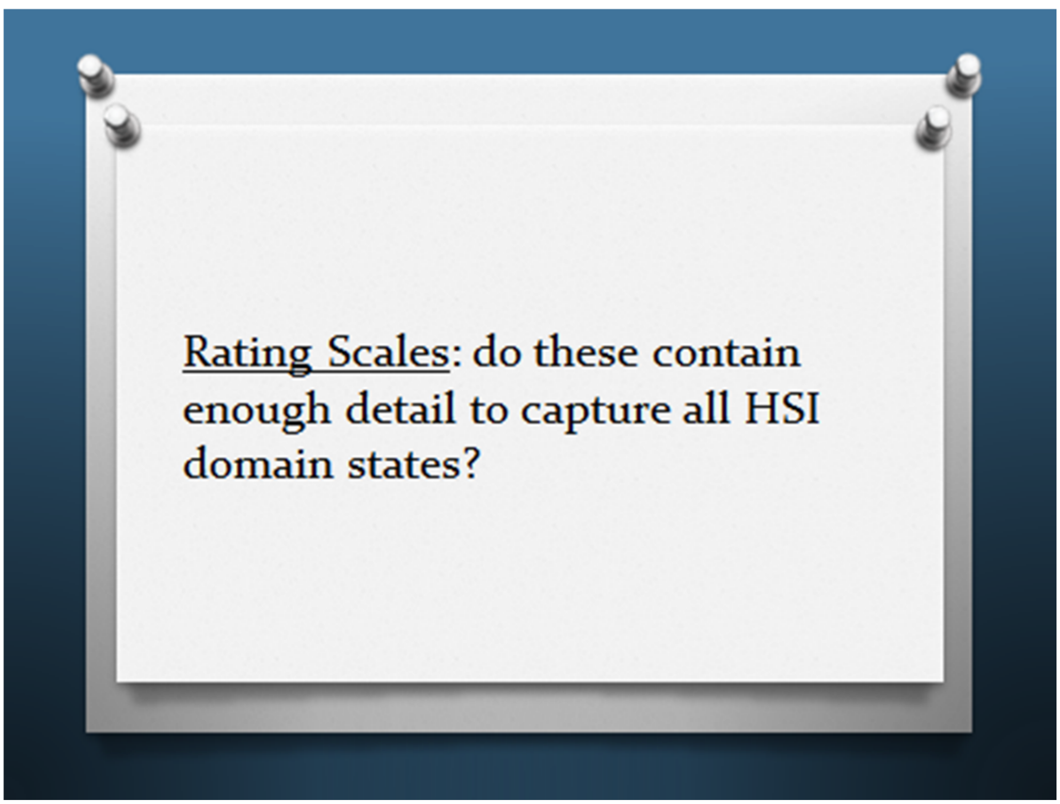

Day Two Wrap Up

WORKSHOP THREE PRESENTATION


Housekeeping
Roles
Participation / Non-attribution
Elluminate Sessions Recorded
Access to Final Product
My Contact Info:


Workshop Goals
Final revisions to rating scale 'guiding criteria' and weighting criteria
Choose a look and feel (3 options)
Choose a system to evaluate for final workshop


problem statement
The acquisitions community would benefit from a common framework to understand, assess and communicate HSI.


Rating Scales: do these contain enough detail to capture all HSI domain states?

Semi-final Rating Scale Definitions

	Total System Performance Implication	Sociotechnical Balance Factor (What is the character of sociotechnical interfaces?)		Human Risk Factor (How are humans treated by the system?)		Accommodation/Utilization Factor (How much of the targeted user population is accommodated?)	
5	Optimizing	(++) Very Good	Sociotechnical interfaces and work design are tailored to account for user capabilities and limitations, across the full range of system tasks, environments and operating conditions.	(++) Completely Acceptable	The system places humans users well within acceptable limits for health, safety and welfare; human functions, work design and work schedule contribute to effective, efficient and safe system performance.	(++) Very Good	Sociotechnical interfaces and work design accommodate the vast majority of the intended users, in the most restrictive measures (typically 99% or 3 standard deviations for given measures).
4	Enhancement	(+) Good		(+) Reasonably Acceptable		(+) Good	
3	Minimal Degradation	Minimally Acceptable	Sociotechnical interfaces and work design account for user capabilities and limitations across essential system tasks, environments and operating conditions.	Minimally Acceptable	The system places humans within acceptable limits for health, safety and welfare; human functions, work design and work schedule do not inhibit effective, efficient and safe system performance.	Minimally Acceptable	Sociotechnical interfaces and work design accommodates the majority of the intended users (typically 86% of the intended user population or 1.5 standard deviations) or equivalent.
2	Moderate Degradation	(-) Poor		(-) Unacceptable		(-) Poor	
1	Severe Degradation	(--)Very poor	Sociotechnical interfaces and work design fail to account for user capabilities and limitations, across multiple essential system tasks, environments and operating conditions.	(--) Extremely Unacceptable	The system places humans well outside of acceptable limits for health, safety and welfare for the given domain; high potential exists for mishap, injury or death.	(--) Very Poor	Sociotechnical interfaces and work design excludes a significant portion of the intended user population (typically < 68% of the intended user population or 1 standard deviation accommodated)

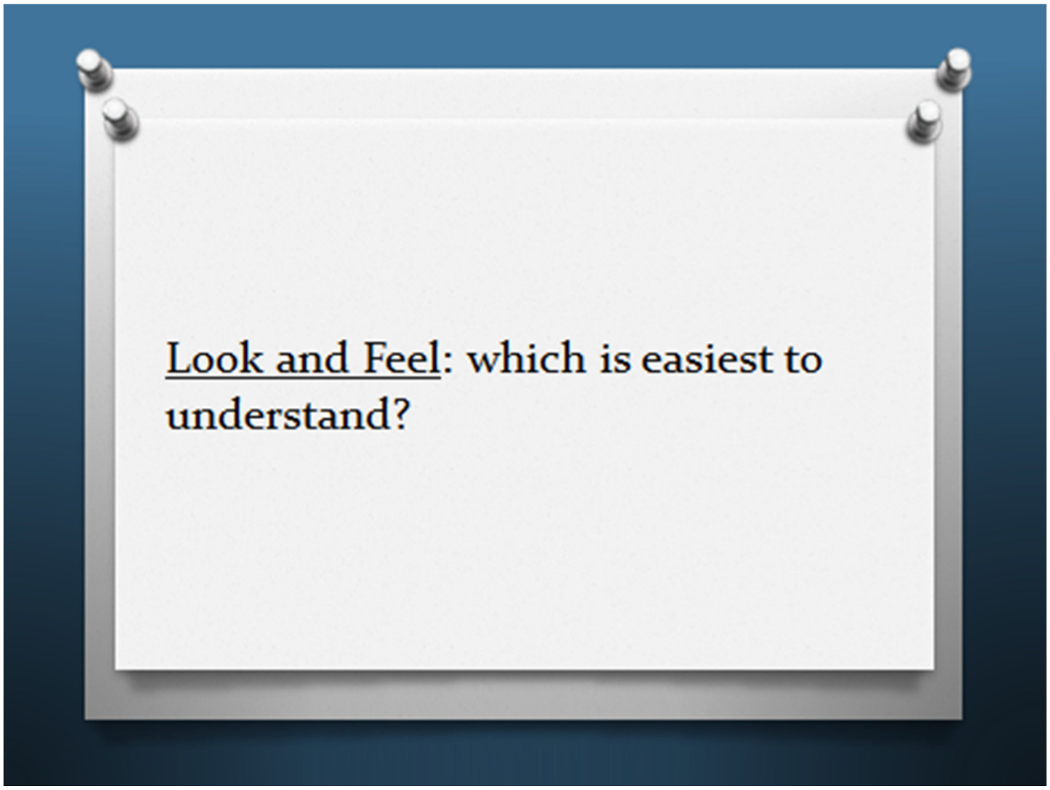
- Minimal acceptability at rating of 3
- *Middle* definitions removed
- Ratings earned by fulfillment of all criteria (similar to OER/EER)

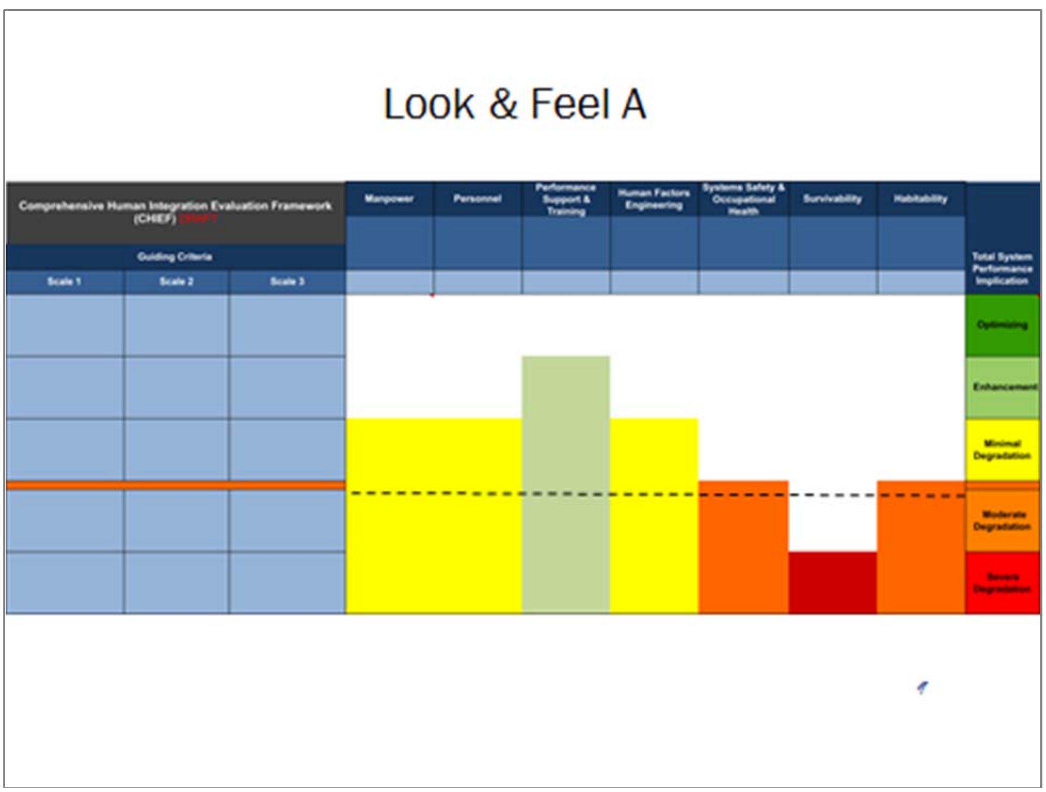
Knowledge Factor for Weighting – 'Glide Slope' Approach

Acquisition Progression Factor (Domain Specific) (Do we have the system-specific HSI knowledge that we would should for the given acquisition phase?)		
Behind (-) The quantity or quality of contributing evidence leading to the domain score is less than expected/required for the current acquisition phase. A discount is assessed on the domain score.	**Concurrent (1)** The quantity and quality of contributing evidence is commensurate with the acquisition phase. No discount or incentive is applied to the domain score.	**Ahead (+)** The quantity and quality of contributing evidence is more than expected/required for the current acquisition phase. An incentive factor is assessed on the domain score.

- Centered on line of minimal acceptability as zero
- <u>Example</u>:
  - ➢ HFE Score of 2 (not good) with AP Factor Behind (-) nets a domain score of 1.8 points out of 5

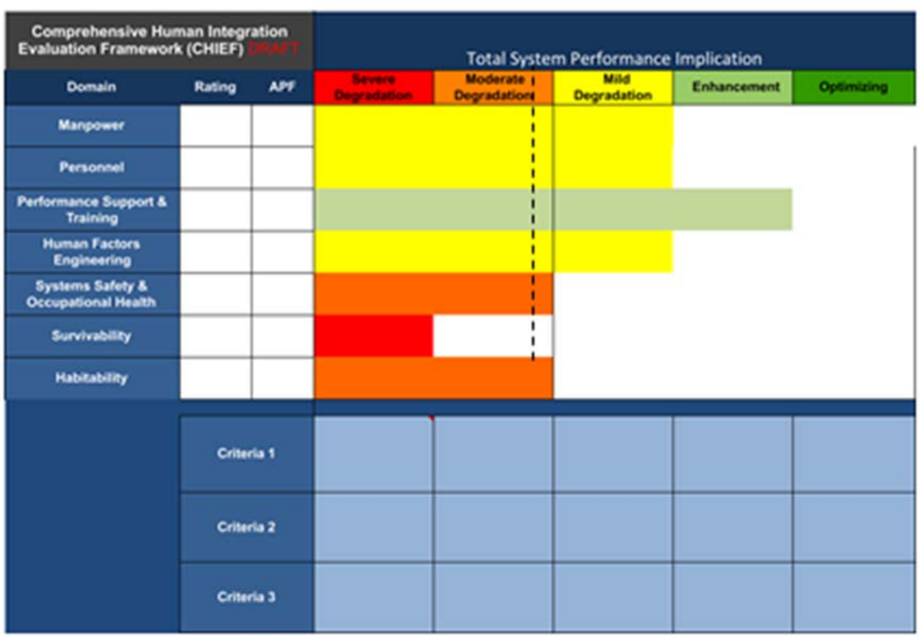
7


Look and Feel: which is easiest to understand?

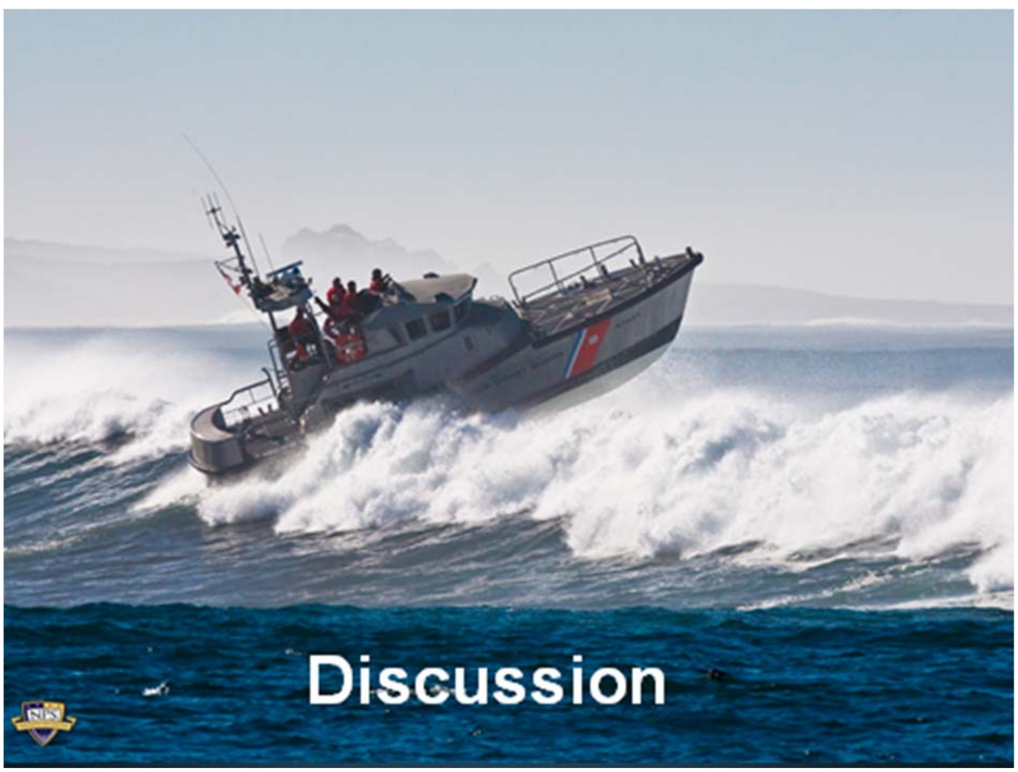

Look & Feel A
Comprehensive Human Integration Evaluation Framework (CHIEF) DRAFT
Guiding Criteria
Scale 1
Scale 2
Scale 3
Manpower
Personnel
Performance Support & Training
Human Factors Engineering
Systems Safety & Occupational Health
Survivability
Habitability
Total System Performance Implication
Optimizing
Enhancement
Minimal Degradation
Moderate Degradation
Severe Degradation

Look & Feel B

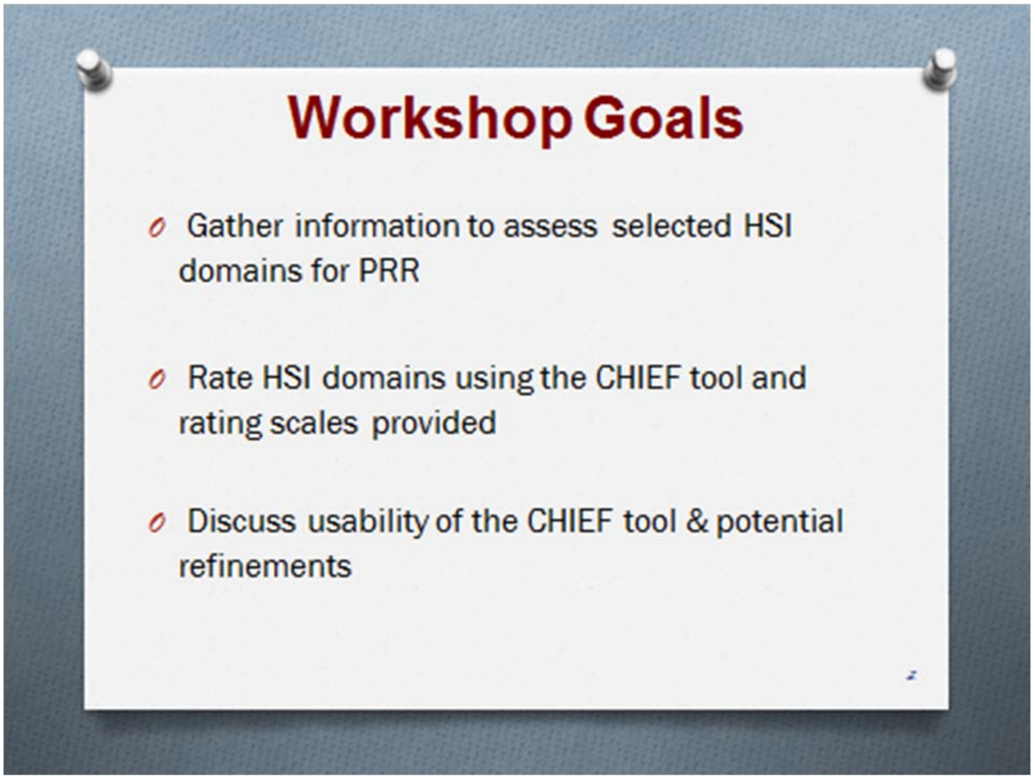
Look & Feel C

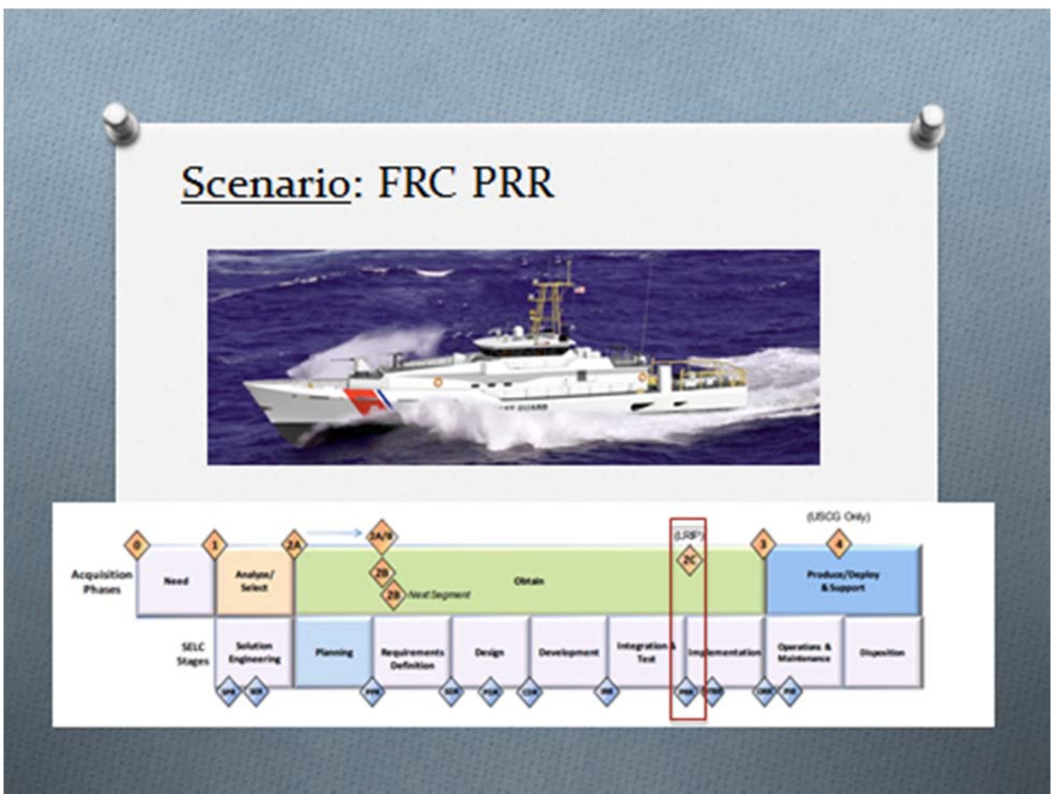


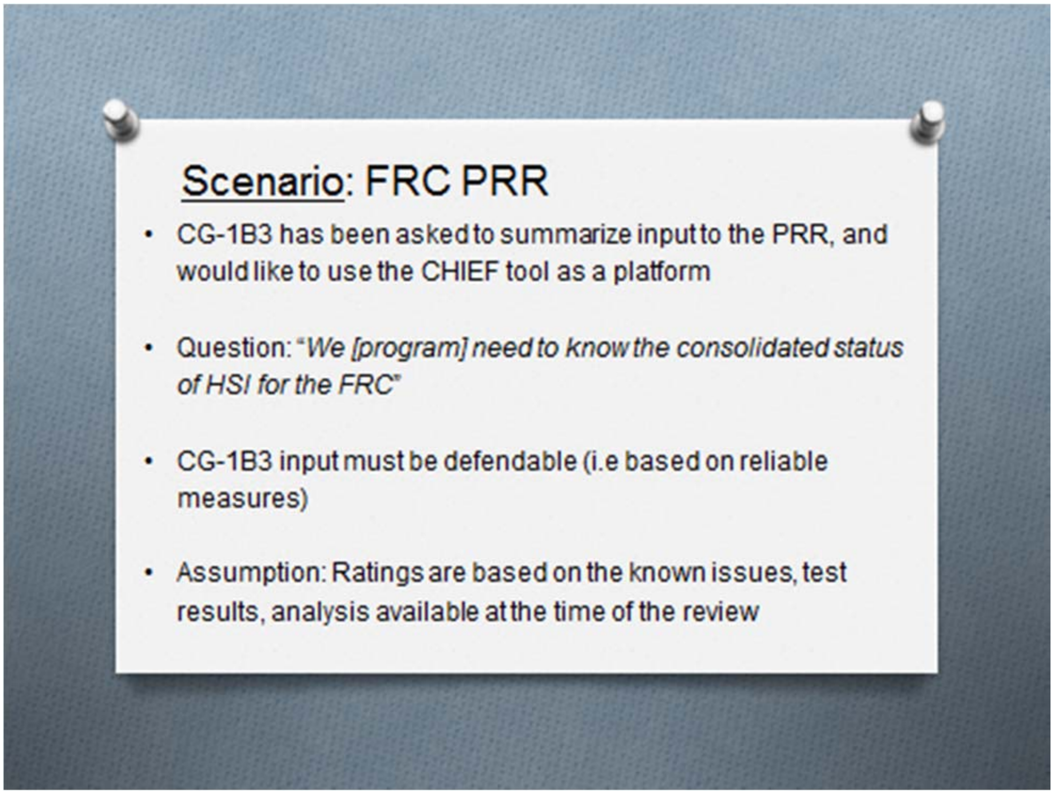
Next Workshop: What system should we rate as a test case?

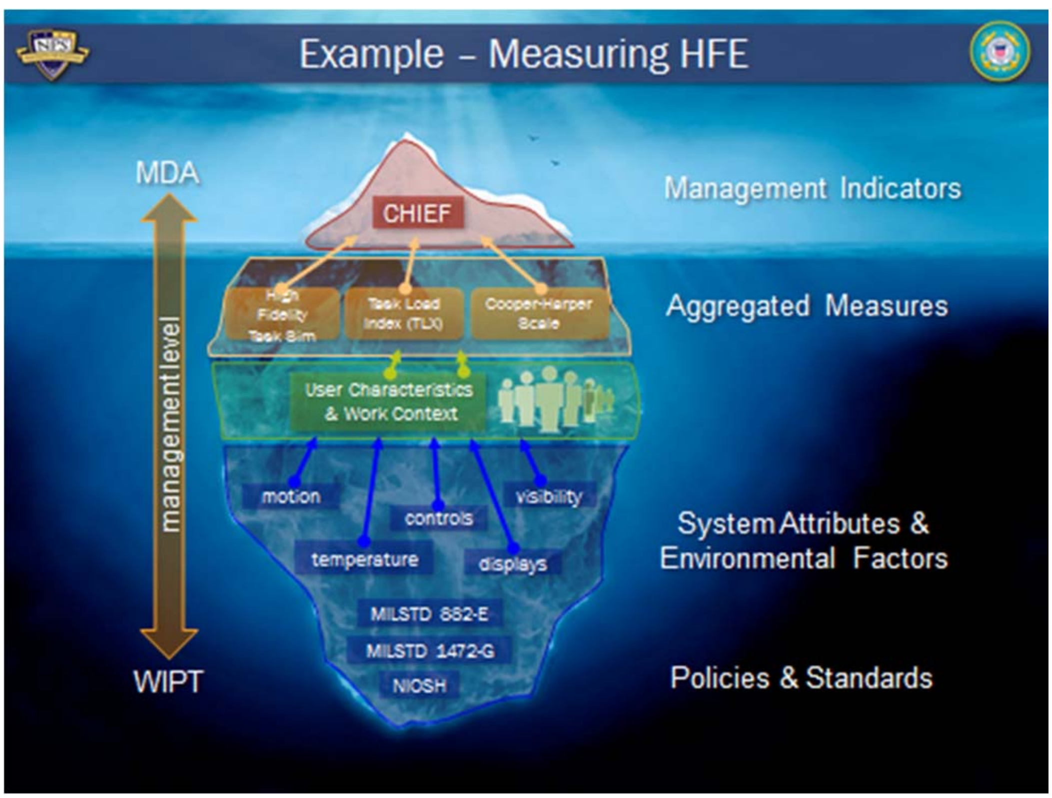


WORKSHOP FOUR PRESENTATION


Workshop Goals
Gather information to assess selected HSI domains for PRR
Rate HSI domains using the CHIEF tool and rating scales provided
Discuss usability of the CHIEF tool & potential refinements


Scenario: FRC PRR
(USCG Only)
(LRIP)
Acquisition Phases
Need
Analyze/ Select
Obtain
Next Segment
Produce/Deploy & Support
SELC Stages
Solution Engineering
Planning
Requirements Definition
Design
Development
Integration & Test
Implementation
Operations & Maintenance
Disposition


Scenario: FRC PRR
• CG-1B3 has been asked to summarize input to the PRR, and would like to use the CHIEF tool as a platform
• Question: "We [program] need to know the consolidated status of HSI for the FRC"
• CG-1B3 input must be defendable (i.e based on reliable measures)
• Assumption: Ratings are based on the known issues, test results, analysis available at the time of the review


Example – Measuring HFE
MDA
management level
WIPT
CHIEF
High Fidelity Task Sim
Task Load Index (TLX)
Cooper-Harper Scale
User Characteristics & Work Context
motion
controls
visibility
temperature
displays
MILSTD 882-E
MILSTD 1472-G
NIOSH
Management Indicators
Aggregated Measures
System Attributes & Environmental Factors
Policies & Standards

Semi-final Rating Scales & Criteria

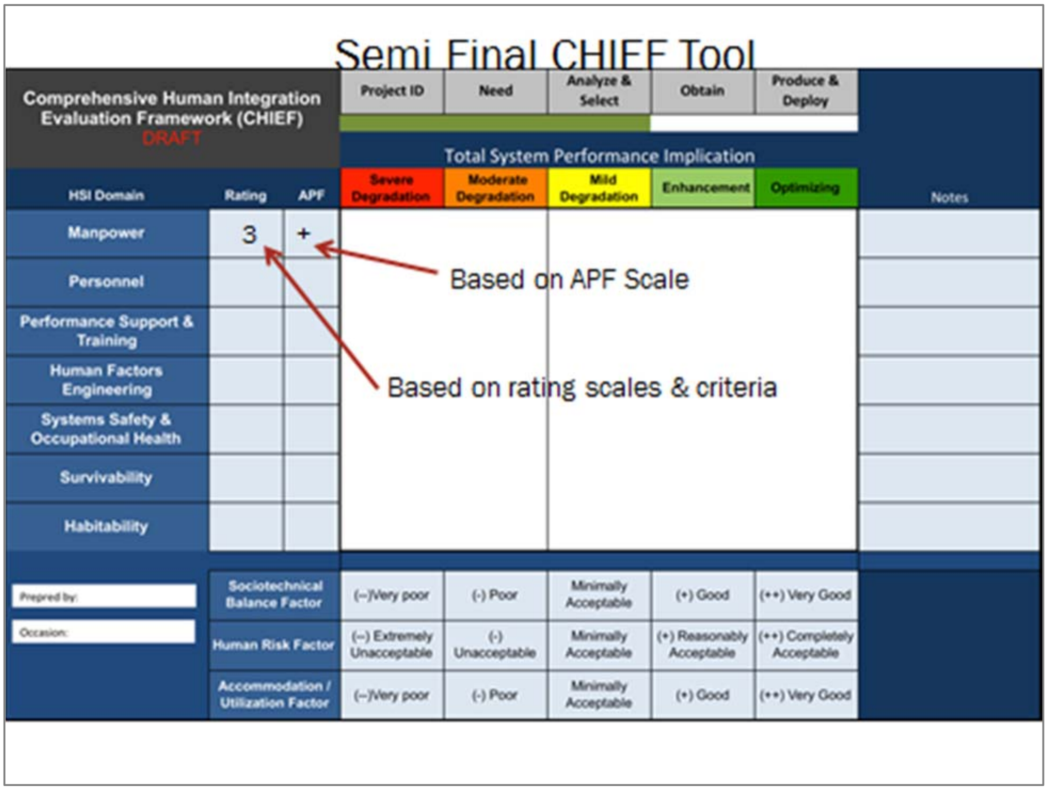
	Total System Performance Implication	Sociotechnical Balance Factor (What is the character of sociotechnical interfaces?)		Human Risk Factor (How are humans treated by the system?)		Accommodation/Utilization Factor (How much of the targeted user population is accommodated?)	
5	Optimizing	(++) Very Good	Sociotechnical interfaces and work design are tailored to account for user capabilities and limitations, across the full range of system tasks, environments and operating conditions.	(++) Completely Acceptable	The system places humans users well within acceptable limits for health, safety and welfare; human functions, work design and work schedule contribute to effective, efficient and safe system performance.	(++) Very Good	Sociotechnical interfaces and work design accommodate the vast majority of the intended users, in the most restrictive measures (typically 99% or 3 standard deviations for given measures).
4	Enhancement	(+) Good		(+) Reasonably Acceptable		(+) Good	
3	Minimal Degradation	Minimally Acceptable	Sociotechnical interfaces and work design account for user capabilities and limitations across essential system tasks, environments and operating conditions.	Minimally Acceptable	The system places humans within acceptable limits for health, safety and welfare; human functions, work design and work schedule do not inhibit effective, efficient and safe system performance.	Minimally Acceptable	Sociotechnical interfaces and work design accommodates the majority of the intended users (typically 86% of the intended user population or 1.5 standard deviations) or equivalent.
2	Moderate Degradation	(-) Poor		(-) Unacceptable		(-) Poor	
1	Severe Degradation	(--)Very poor	Sociotechnical interfaces and work design fail to account for user capabilities and limitations, across multiple essential system tasks, environments and operating conditions.	(--) Extremely Unacceptable	The system places humans well outside of acceptable limits for health, safety and welfare for the given domain; high potential exists for mishap, injury or death.	(--) Very Poor	Sociotechnical interfaces and work design excludes a significant portion of the intended user population (typically < 68% of the intended user population or 1 standard deviation accommodated)

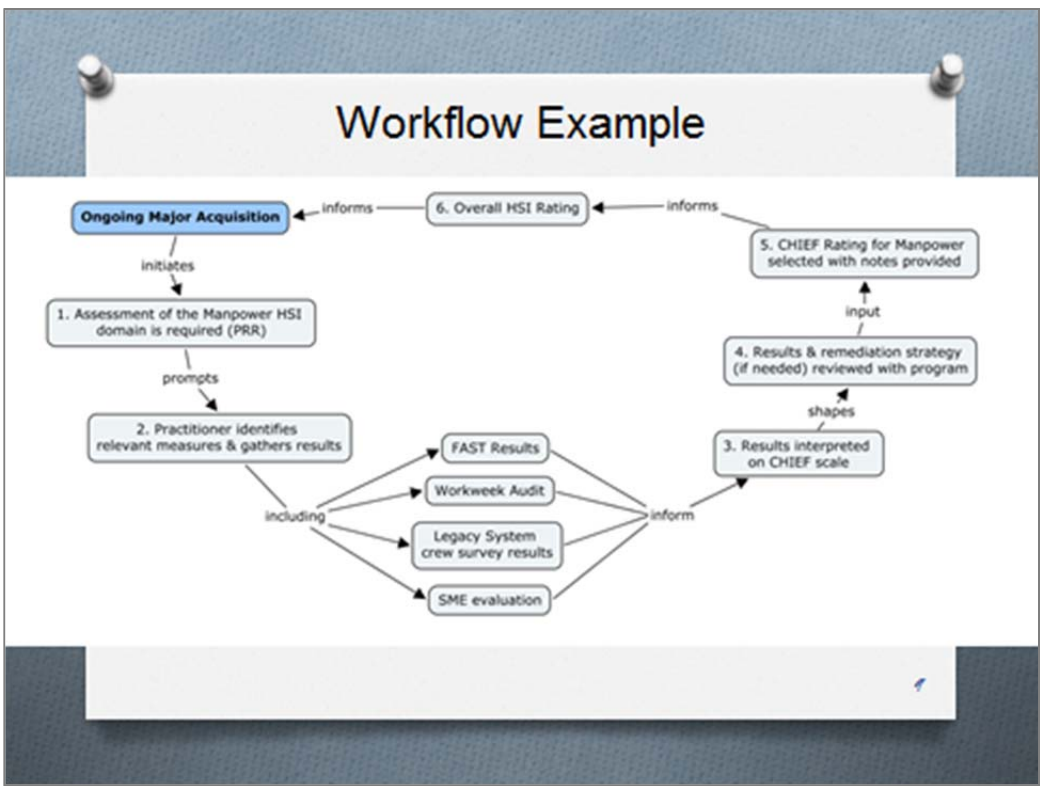
- Minimal acceptability at rating of 3
- Ratings assigned by fulfillment of all criteria in each block (similar to OER/EER)

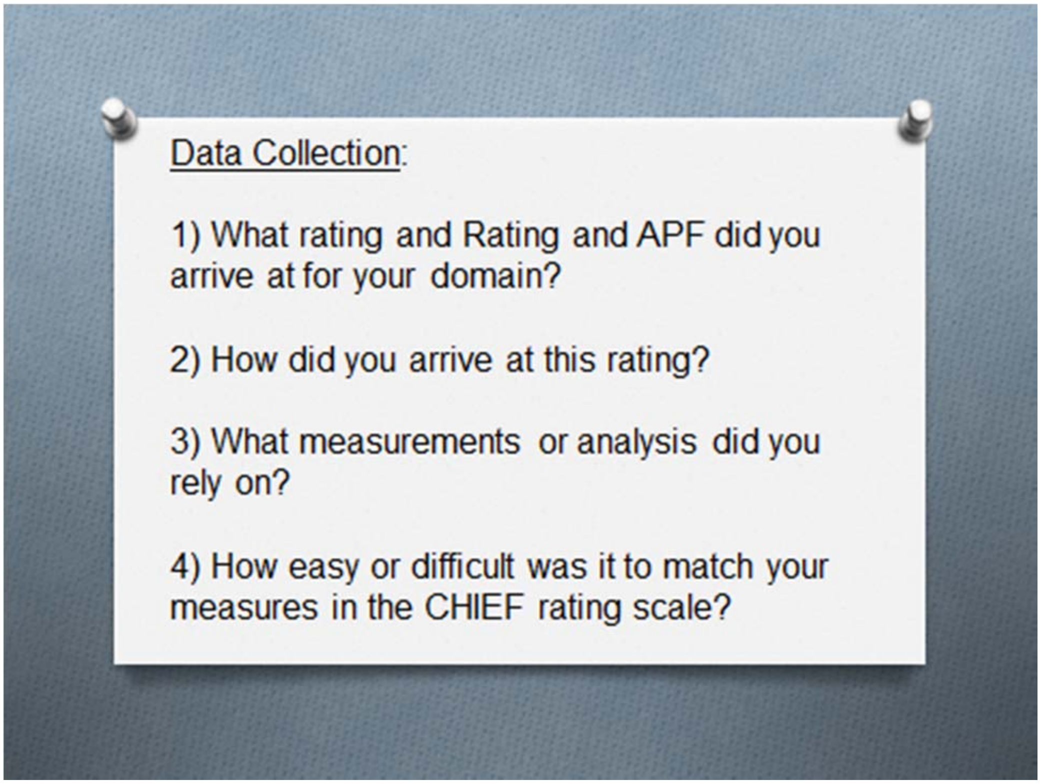
Acquisition Progression Factor – 'Glide Slope' Approach

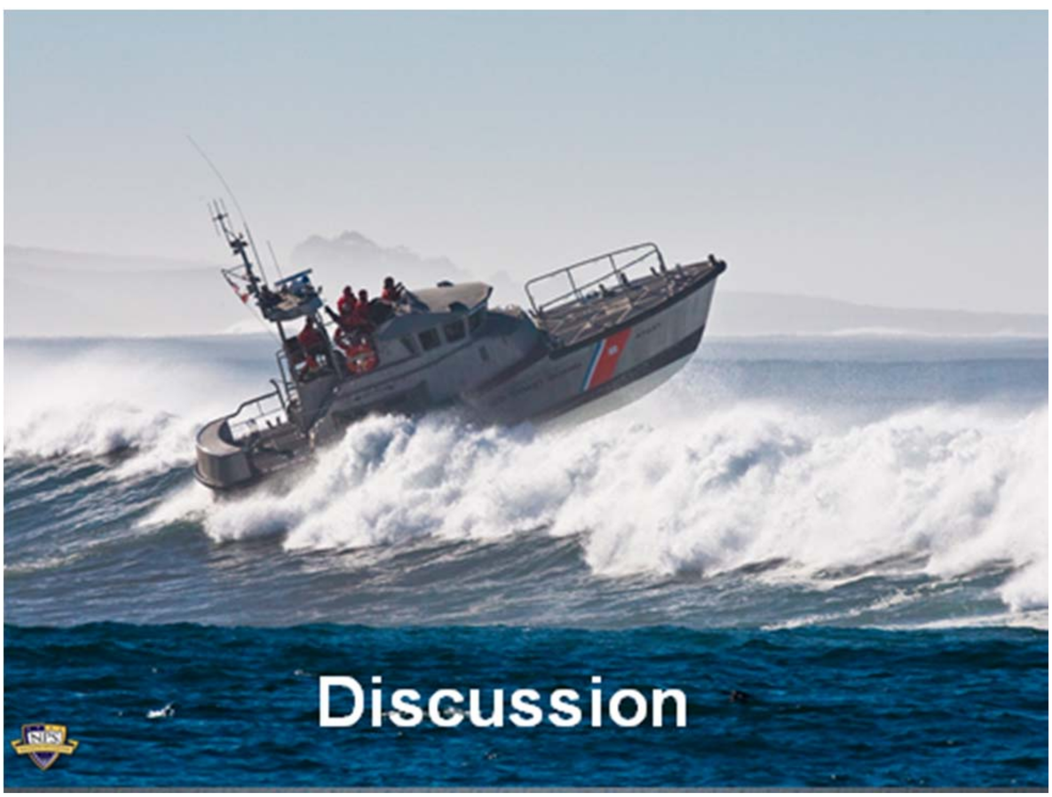
Acquisition Progression Factor (Domain Specific) (Do we have the system-specific HSI knowledge that we would should for the given acquisition phase?)		
Behind (-) The quantity or quality of contributing evidence leading to the domain score is less than expected/required for the current acquisition phase.	**Concurrent (=)** The quantity and quality of contributing evidence is commensurate with the acquisition phase.	**Ahead (+)** The quantity and quality of contributing evidence is more than expected/required for the current acquisition phase.

- <u>In practice</u>:
  - ➤ We don't know as much as we should = AP Factor Behind (-)
  - ➤ We are 'on track' for HSI knowledge = AP Factor neutral
  - ➤ We know more than we would expect to at the given acqu phase = AP Factor Behind (+)


Semi Final CHIEF Tool
Comprehensive Human Integration Evaluation Framework (CHIEF)
DRAFT
Project ID
Need
Analyze & Select
Obtain
Produce & Deploy
Total System Performance Implication
HSI Domain
Rating
APF
Severe Degradation
Moderate Degradation
Mild Degradation
Enhancement
Optimizing
Notes
Manpower
3
+
Based on APF Scale
Personnel
Performance Support & Training
Human Factors Engineering
Based on rating scales & criteria
Systems Safety & Occupational Health
Survivability
Habitability
Prepred by:
Occasion:
Sociotechnical Balance Factor
(--)Very poor
(-) Poor
Minimally Acceptable
(+) Good
(++) Very Good
Human Risk Factor
(--) Extremely Unacceptable
(-) Unacceptable
Minimally Acceptable
(+) Reasonably Acceptable
(++) Completely Acceptable
Accommodation / Utilization Factor
(--)Very poor
(-) Poor
Minimally Acceptable
(+) Good
(++) Very Good


Workflow Example
Ongoing Major Acquisition
informs
6. Overall HSI Rating
informs
5. CHIEF Rating for Manpower selected with notes provided
initiates
1. Assessment of the Manpower HSI domain is required (PRR)
input
4. Results & remediation strategy (if needed) reviewed with program
prompts
shapes
2. Practitioner identifies relevant measures & gathers results
FAST Results
3. Results interpreted on CHIEF scale
Workweek Audit
including
inform
Legacy System crew survey results
SME evaluation


Data Collection:
1) What rating and Rating and APF did you arrive at for your domain?
2) How did you arrive at this rating?
3) What measurements or analysis did you rely on?
4) How easy or difficult was it to match your measures in the CHIEF rating scale?


Discussion

APPENDIX C – DESIRED CHARACTERISTICS FOR CHIEF SOFTWARE

- Basic Functionality: CHIEF software will provide a web-based graphical user interface and database for collecting and assessing HSI information during system acquisition. Users will be able to create, edit, approve and track HSI performance ratings and supporting information for federal acquisition programs, based on the CHIEF.

- Expected User Group: The CHIEF user group will include HSI practitioners, HSI managers and other acquisition professionals from a variety of disciplines. Users will include federal government employees, military members, military contractors and vendors.

- Interface and Display Modes: Information entered into CHIEF will serve different managerial levels, across multiple functional groups. CHIEF software will include specific interface and display modes to suit the needs of these user sub-groups. CHIEF information (e.g., HSI domain definitions, rating scale criteria, rating supporting information) will be rapidly accessible as "display-on-demand" information using hyperlinks, mouse-over or similar software functionality.

- Information Input: HSI practitioners will carry out the bulk of CHIEF data entry, edits, and updates. File formats are expected to include text files, spreadsheets, photographs, video, scans, and electronic presentations. Additional formats may be required.

- Information Validation: HSI managers will validate individual HSI domain ratings and supporting information entered by HSI practitioners. Acquisition managers will access, review and approve top level information.

- Information Export: Reports and summary information from CHIEF software must be exportable in common formats including commercially-available word processing, spreadsheet, presentation and document display software.

- Workflow Automation: Data entry will be implemented according to the standardized CHIEF workflow, using government approved reference materials and standards. The software should automate the workflow through the use of pre-positioned information, drop-down menus, links or similar functionality.

- Access Control: An access hierarchy will be required to manage each user's ability to view, edit and control CHIEF information. Access to CHIEF software will be controlled by the appropriate authority within the government acquisitions organization.

- IT Enterprise Compliance: CHIEF software will reside on government equipment and networks. Users and administrators will be expected to have access to the Coast Guard data network or analogous DOD systems (as appropriate).

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